Presentation to IRAC of Detailed Technical Analysis of Systems Studied in NTIA Reports

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John McCorkle
Cofounder and CTO
John@XtremeSpectrum.com

XtremeSpectrum, Inc.
8133 Leesburg Pike, Suite 700
Vienna, VA 22182
(703) 269-3000

Introduction
This Presentation Will Show

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- **No Peer-to-Peer Restrictions are needed**
  -- A Simple Restriction On Tower Mounted UWB Devices is Plenty
  - Sound technical analysis supports that a spectral mask provides all the needed protection to allow UWB devices to operate outdoors.
- **Outdoor Class-B UWB at any height and scenario is safe for GPS**
  - Numerous reports and studies present a consistent picture of the interference mechanisms of UWB on GPS receivers
  - The 35 dB down from Class-B accomplishes the needed protection
- **Outdoor Class-B UWB at any height is safe for all systems studied in NTIA report**
  - Assumptions that changed will be highlighted in following slides
- **Aggregation is not a factor**
  - Numerous reports and studies present a consistent picture showing the cumulative effects of multiple UWB devices are dominated by closest emitters
  - Experience from PC's is that aggregation is not an issue.
- **Emissions and Aggregation from a PC are representative**
  - UWB signals are similar from those of PC's and other typical radio signals.
  - If a device is not bothered by PC's, then it won't be bothered by UWB

NTIA Reports on Impact of UWB on Non-GPS Government Systems

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- **Two documents (several hundred pages each)**
  - NTIA report 01-43, “Assessment of Compatibility Between Ultrawideband Devices and Selected Federal Systems”
  - NTIA report 01-383, “The Temporal and Spectral Characteristics of Ultrawideband Signals”
- **Evaluated 13 systems with variations on most**
- **Described analysis procedure and provided access to the Excel spreadsheets used to perform the analysis**
- **Concluded that UWB might be OK above 3 GHz**

Outline

- NTIA Study
  - SNR *not Noise Figure* as metric for harmful interference
  - Lack of Aggregation

Pg	GHz	System	Outdoor Limit Required	Limit Relative to Class-B
14	5.6-5.65	TDWR Terminal Doppler Weather Radar	– 41.3 dBm/MHz	0 dB
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* - RTCA/GPSIC limits

- Other Topics
  - Similarities to Emissions from PC's
  - UWB does not imply spectral lines

The Metric For Evaluating Harmful Interference --Receiver Noise is Not the Whole Story

- **The NTIA analysis was well done as far as it went, but ….**
  - It used the impact to system noise figure as the sole basis of analysis – which is inadequate.
- **Key-- choose a metric representative of system functionality**
  - The real-world limitations on RF systems performing their function is the operational signal-to-noise ratio (SNR) being above a threshold
- **The following cases must be considered**
  - The operational SNR is above the needed threshold
    - Here, the impact to the effective receiver noise figure not harmful.
  - The scenario geometry is blocking the signal
    - Here, the system would fail regardless of the affect UWB had.
  - The scenario geometry causes a human radiation hazard
    - Here, it is not fair to impose limits based on distances that put the user at risk
  - The system functionality is primarily governed by the receiver noise.
    - Here, the limits can be calculated based on the rise in effective noise figure as NTIA did

Radiation Hazards

- **Aircraft – 300 V/m peak**
  - FAA, 14 CFR Parts 21 & 25, Federal Register May 16, 1988
  - ASR-9 – 1.4 km
  - TDWR – 4.3 km
  - ARSR-4 – 5.8 km
  - NEXRAD – 4.5 km
- **Critical Medical Electronic Devices – 200 V/m peak**
  - AF report SAM-TR-76-4 (e.g. Pacemakers etc.):
- **Personal Exposure Limit (PEL) – 1mW/cm^2**
  - DOD instruction 6055 and ANSI C95.1-1982
- **Fuels – 3.1KV/m peak**
  - DNA 4284-F-SAS-1 Dec 1979
- **Explosives – 12.4 KV/m**
  - DNA 4284-F-SAS-1 Dec 1979

It is not reasonable base regulations on geometries that put the UWB user in field strengths not safe for pacemakers

Assumptions That Changed From NTIA Analysis

- Add GPS Notch -- for both noise and spectral lines
- Distinguishing between potentially of tickling a receiver vs harmful interference
- Signal Strength – (i.e. Affect of Victim System Transmit Power)
  - NTIA ignored the victim system's SNR and its affect on system performance
  - Example - Headlights in the Fog similar to "clutter limited" radar.
    One's ability to see in fog is not governed by the sensitivity of the eye, but by the "clutter" (i.e. the reflections from fog droplets). Increasing the brightness of the headlights simply makes both the clutter (fog) and the desired signal (what you want to see) stronger. It does nothing to improve the signal to "noise" ratio and change how well you can actually see. In the same way, many radar systems operate in a "clutter limited" regime where the effective "noise" is really clutter (proportional to the transmit power) and not the receiver-noise. The radar's receiver noise is immaterial, just like my eye sensitivity is immaterial when driving through fog.
  - Because it ignored the transmitter (or desired signal), Even if the received signal was more than 1000 times stronger than the received noise, the NTIA report would still classify the interference as intolerable – Which is clearly not reasonable.
- Antenna Beam Pattern - FSS
  - NTIA used the standard procedure of modifying the 25.209 FCC beam-shape mask to get a beam shape,
  - But the resulting beam shape breaks the law of conservation of energy and does not represent reality, especially on the skirts of the main lobe.
  - Therefore, real beam patterns were used in the augmented analysis

Broad Summary

- **Typical Mobile systems (aircraft, ships):**
  - Case 1: Long-range scenarios where functionality is receiver-noise limited
    - End up being too distant from UWB devices for them to have any impact.
  - Case 2: Short-range scenarios, close enough to UWB sources to have slightly increased the receiver noise floor,
    - End up with the system SNR so high, that the system functions normally regardless of the UWB signal level.
- **Typical Land-based systems (weather radar, airport systems)**
  - Need to site their systems to point above buildings to see targets and avoid blockage
  - The SNR is governed by the strong signals NOT the noise floor
    – Signals are large relative to receiver noise and noise from potential UWB devices.
- **Details provided in following slides on each system**

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  - Lack of Aggregation

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- Other Topics
  - Similarities to Emissions from PC's
  - UWB does not imply spectral lines

Illustration of Non-Aggregation

- **Illustration is of interference to a GPS-enabled handset in a hotel room where a UWB WPAN (Wireless Personal Area Network) is in every room in the hotel.**
- **The table on next page shows the aggregate signal levels received as a function of how many rooms away the other UWB transmitters are.**
- **For each WPAN, the UWB device closest to the GPS handset is the one transmitting at the time the handset initiates a GPS measurement.**
- **The closest WPAN is in the same room -- we assign $1/R^2$ propagation loss since it is line-of-sight.**
- **Every room is transmitting at worst case, continuous full power levels. (i.e. 1.175 nW/MHz, which is -18dB below Part 15 Class B levels).**

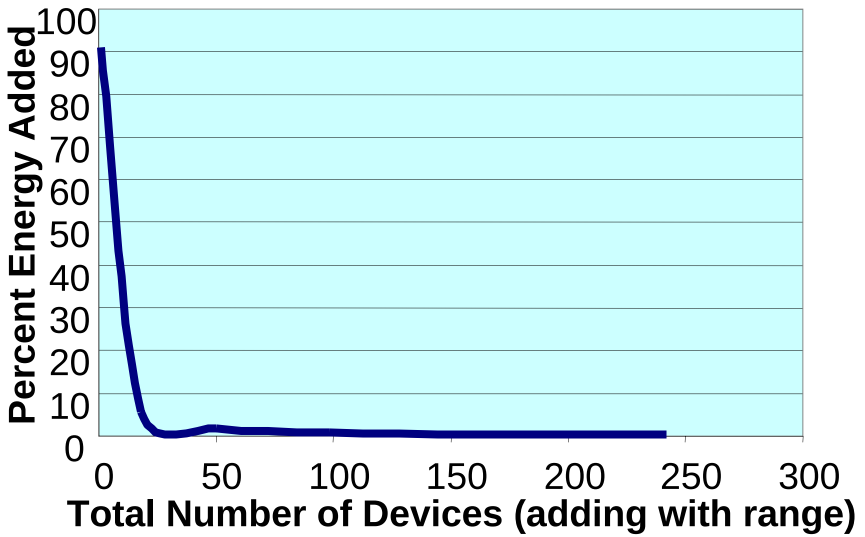
Hotel Illustration Table Showing Non-Aggregation

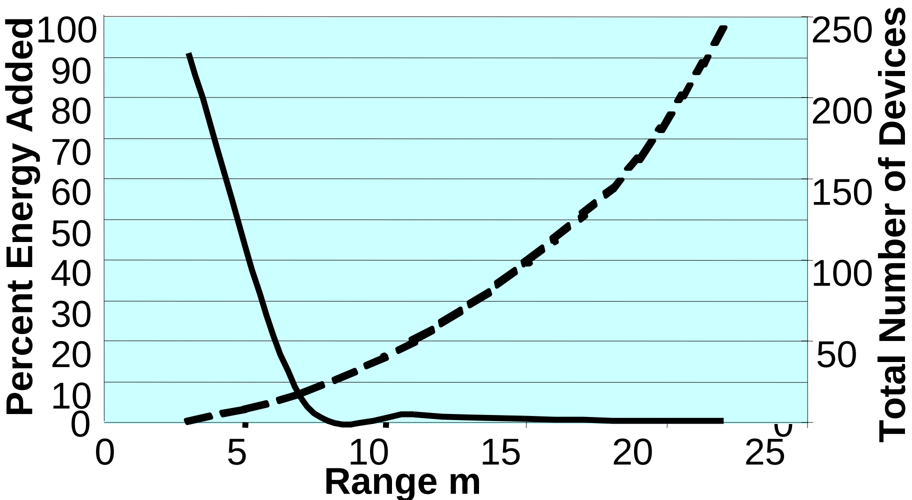
WPAN #	Range to Victim Receiver m	Power received by Victim Receiver picowatt/MHz	% of total energy received by victim receiver	Accumulated Power Received By Victim Receiver	Location of WPANs
1	3	0.029506	90.957	0.029506	Net in same room
2-18	7	0.001880	5.796	0.031386	17 Nets, 8 in adjacent rooms (left, right, above, below, left-above, right-above, left-below, right-below) PLUS 9 across the hall
19-50	11	0.000580	1.789	0.031966	32 Nets 16 in 2nd adjacent Rooms + 16 across hall
51-98	15	0.000252	0.776	0.032218	48 Nets, 24 in 3rd adjacet rooms + 24 across hall
99-162	19	0.000130	0.402	0.032348	64 Nets 32 in 4th adjacent rooms + 32 across hall
163-242	22	0.000091	0.280	0.032439	80 Nets 40 in 5th adjacent rooms + 40 across hall
Total Interference = .032439 picowatts/MHz = -104.9 dBm/MHz =1.099 times the power from the closest emitter					

- **Note that by the time we get 4 rooms away, there are 64 simultaneous transmitters at equal distance, yet they produce less the 1/2 percent of the total interference power.**
- **Even though interference adds linearly, received interference does not increase linearly as UWB emitters spread over large regions.**
- ***<u>The key point here is that more distant WPANs become insignificant.</u>***

Plot of Non-Aggregation from Previous Slide

- **Yes, Power adds Linearly**
- **But, Clearly as the device numbers grow The energy added becomes insignificant**
- **i.e. No Aggregation**





Summary of Illustration of Non-Aggregation

- **Every Day Similarities**
  - Even if all the TVs in a hotel are playing, at most you might barely hear your immediate neighbors', but you don't hear any others -- and you certainly don't hear any of these TVs from anywhere outside the hotel, or from inside the hotel next door.
  - If you were in a packed stadium with 50,000 other people, and every other person decided to whisper to his neighbor at once, you would not get blasted by the aggregation of 25000 people whispering, each whisper would be too quiet to get far enough to aggregate.
- **Similarly, UWB does not raise the noise floor across a city**
  - Because of the combination of the self-limiting density, and the naturally occurring attenuation which causes only the closest emitter to dominate.
- **The Aggregation Analysis in the NTIA reports gives same result**
  - The little energy radiated, dissipates in very short distances due to real-world attenuation and random reflections.
  - Only the closest transmitters affect the received signal level (for all practical purposes)
  - On the ground, where units can be close, only the closest transmitters matter.
    - Therefore single-emitter analysis can be used to understand interference potential.
  - Aircraft are too far away when flying or have too high SNR's when landing, so aggregation is not an issue.
- **The FCC came to the same conclusion also**
  - The FCC Commission's Technology Advisory Council, Spectrum Management Focus Group, reviewed analysis papers from four firms and "concluded that there would be no significant rise in the RF noise floor. Rather, that noise floor would be set by the closest UWB transmitters. " (para 46 NPRM)

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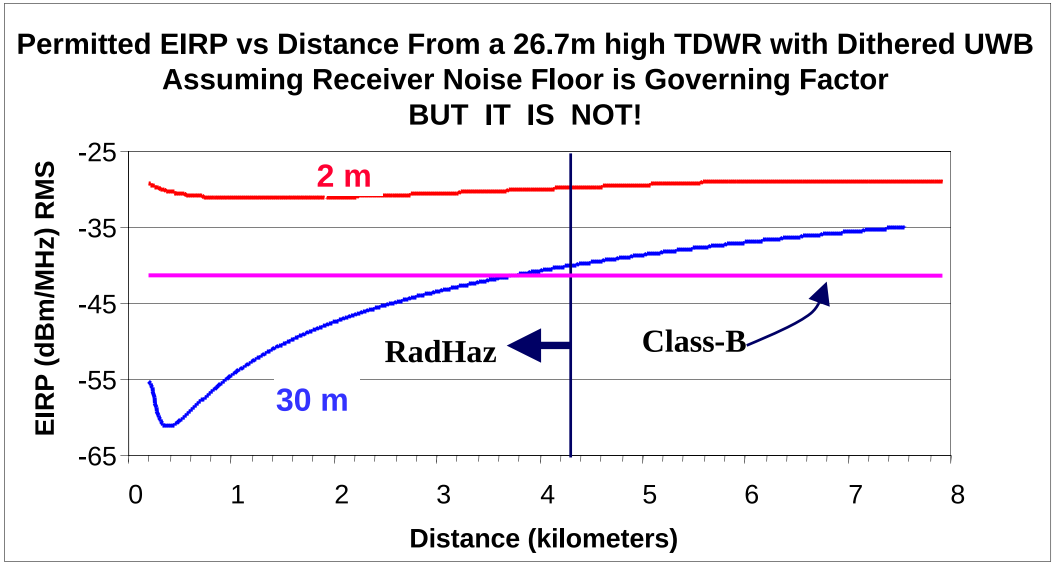
- **Other Topics**
  - **Similarities to Emissions from PC's**
  - **UWB does not imply spectral lines**

Terminal Doppler Weather Radar (TDWR) - What it is

- **Its function is to detect wind shear from 300-19,200 feet altitude in the vicinity of an airport**
- **It is best located 8-10 mi from runway so that buildings and terrain do not block coverage over the runways. It must be sited to see approach, runway, and departing paths.**
- **Specifications are:**
  - 5.6 GHz
  - 150 KW peak
  - 50 dB gain Antenna (0.55° spot beam)
  - -110 dBm/910KHz noise floor
- **TDWR is an extremely powerful radar –radiating 15 GW peak EIRP in the main beam.**
- **The RadHaz (200 V/m) distance for pacemakers is 4.3 km**
  - To a 30m building from a 26.7 m TDWR at 0.2°
- **It is circularly polarized and has a 3 dB coupling loss to UWB signals**
- **It is designed to be clutter limited, not noise figure limited**

TDWR NTIA Analysis

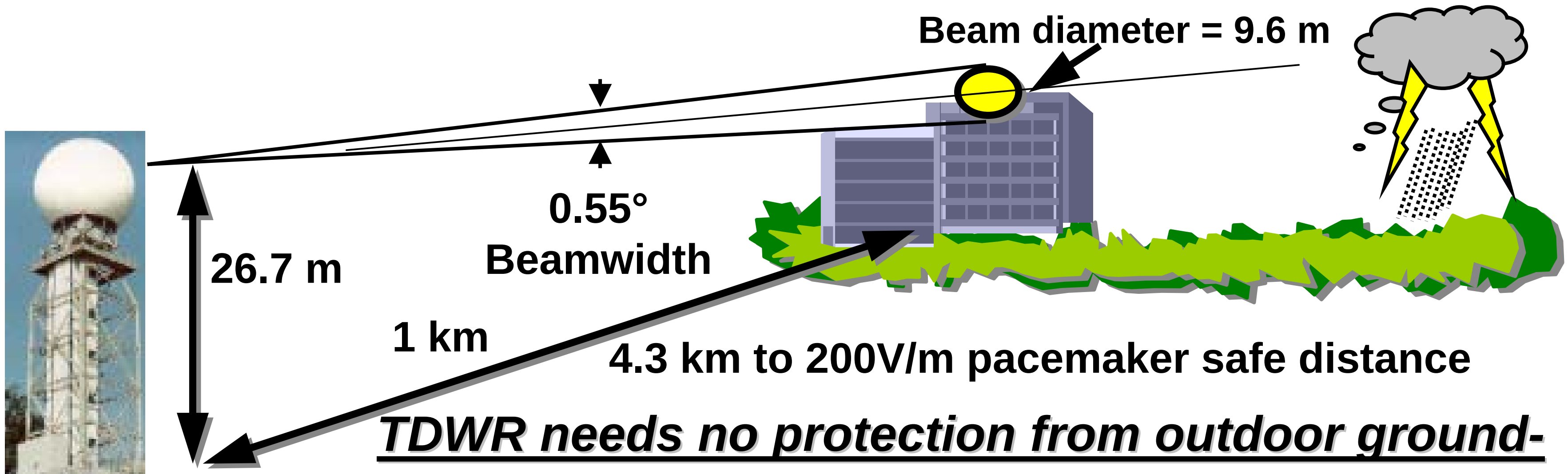
- **Using the NTIA noise-only analysis approach shows**
  - Class B UWB at 2m height has no impact at any range
  - Class B UWB at 30m height has no impact at the range where users with pacemakers would be in danger



- **BUT…**
  - At a range where the 30 meter building location would cause a problem, it would already be blocking the view of the runway
  - The noise is caused by its own transmitter, not the receiver noise figure.

TDWR
Limitation is not the noise floor

- **Microbursts have a radar cross-section (RCS) of up to 10 dBz while outflow boundaries and wind shear are larger.**
- **Calculations show that target returns for weather present high enough S/N ratios that the noise floor is of no concern**
  - >40dB margin to a 0 dBz microburst using uncorrected NTIA values for a 30 m high UWB device,
  - i.e. there are no problems operating the radar even if there would be a 21.5 dB increase in the receiver noise floor.



<u>TDWR needs no protection from outdoor ground-level or elevated Class-B UWB devices</u>

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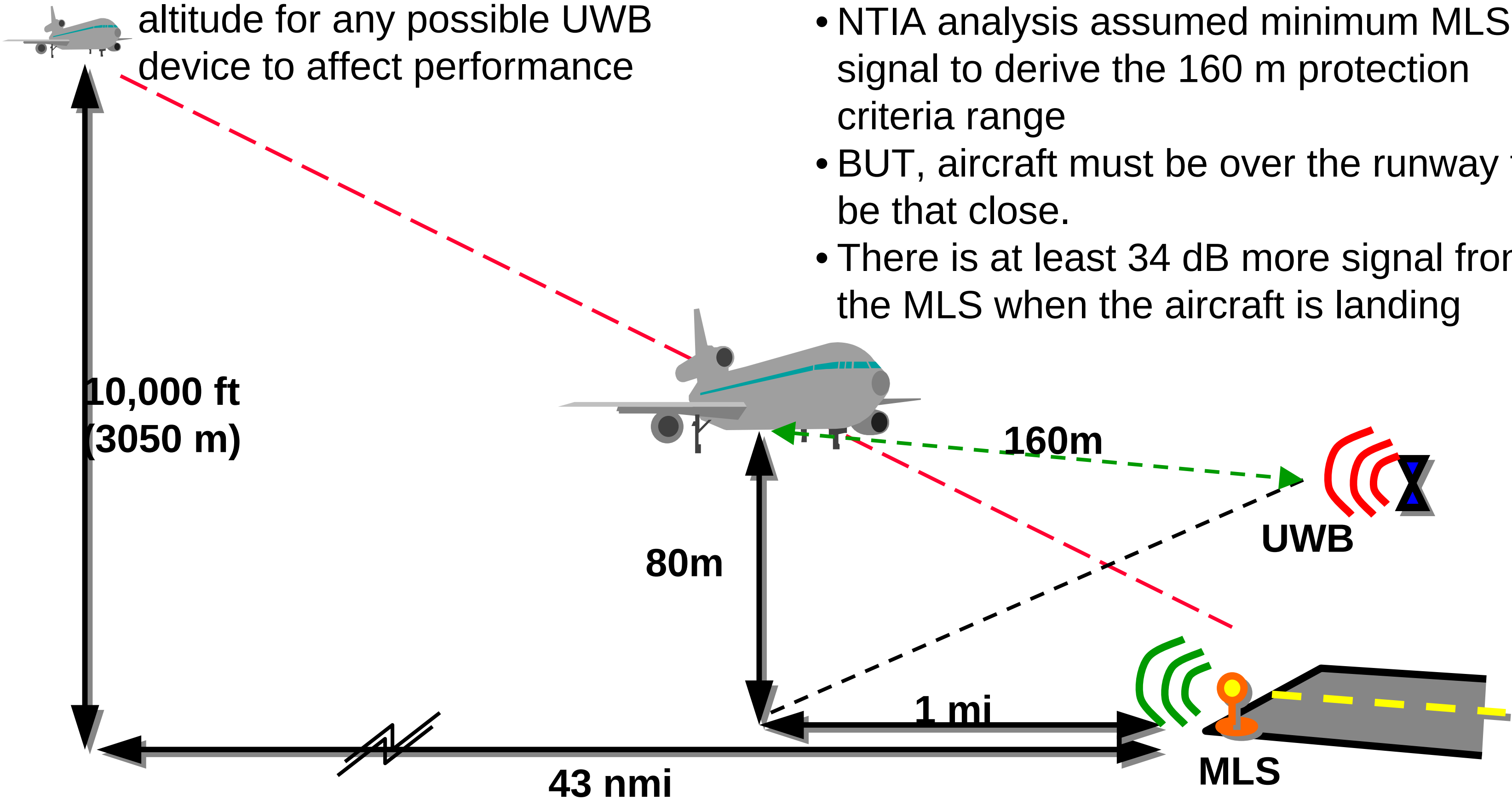
Airborne Receiver Example: Microwave Landing System (MLS)

When the aircraft is at the maximum range (43 nautical mi) of the MLS (e.g. minimum MLS signal) the aircraft is at too great an altitude for any possible UWB device to affect performance

- NTIA analysis assumed minimum MLS signal to derive the 160 m protection criteria range
- BUT, aircraft must be over the runway to be that close.
- There is at least 34 dB more signal from the MLS when the aircraft is landing



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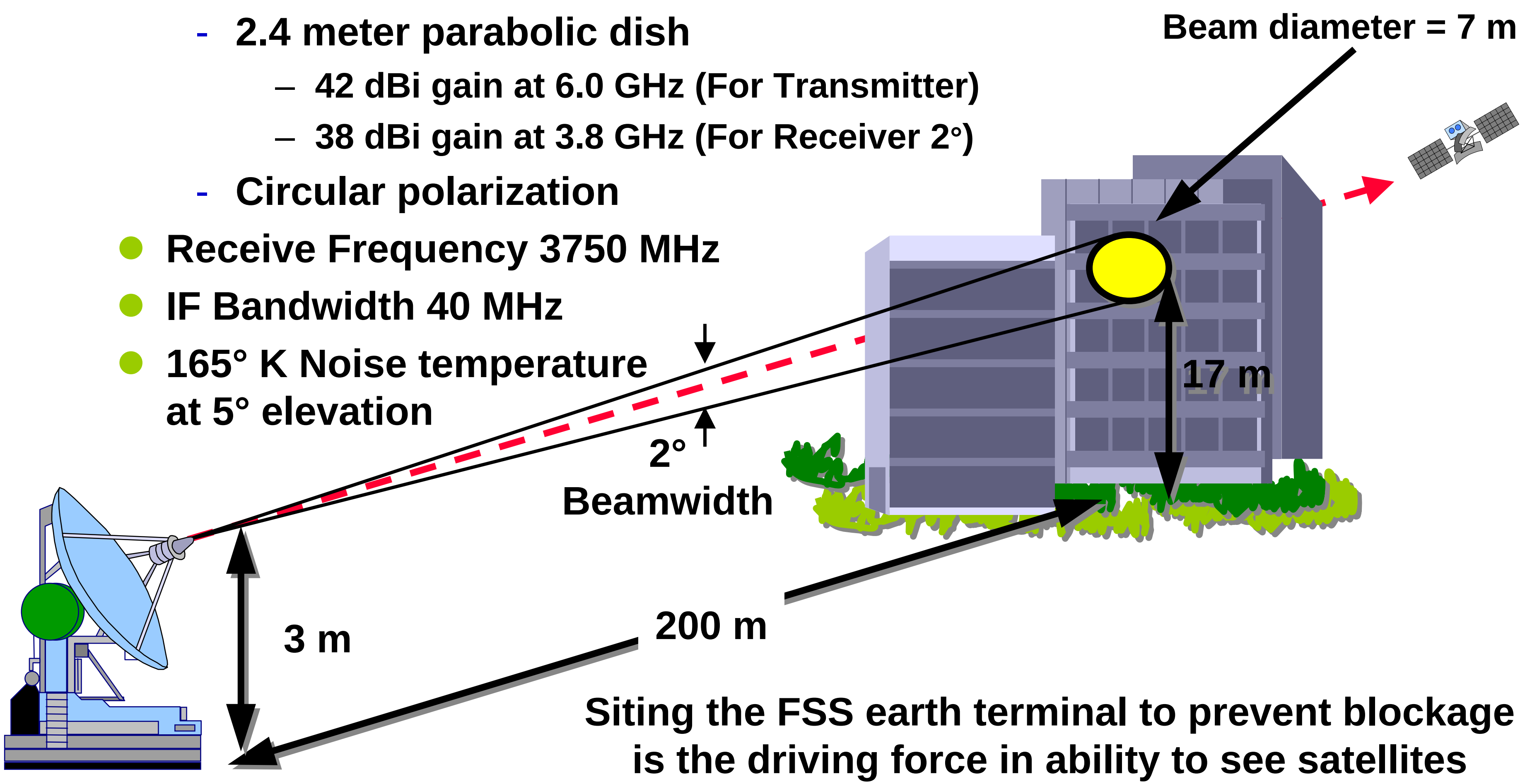
Fixed Satellite Service -- What it is

- **Geostationary satellite downlink of data, voice, and video**
  - **Antenna**
    - **2.4 meter parabolic dish**
      - **42 dBi gain at 6.0 GHz (For Transmitter)**
      - **38 dBi gain at 3.8 GHz (For Receiver 2°)**
    - **Circular polarization**
  - **Receive Frequency 3750 MHz**
  - **IF Bandwidth 40 MHz**
  - **165° K Noise temperature at 5° elevation**

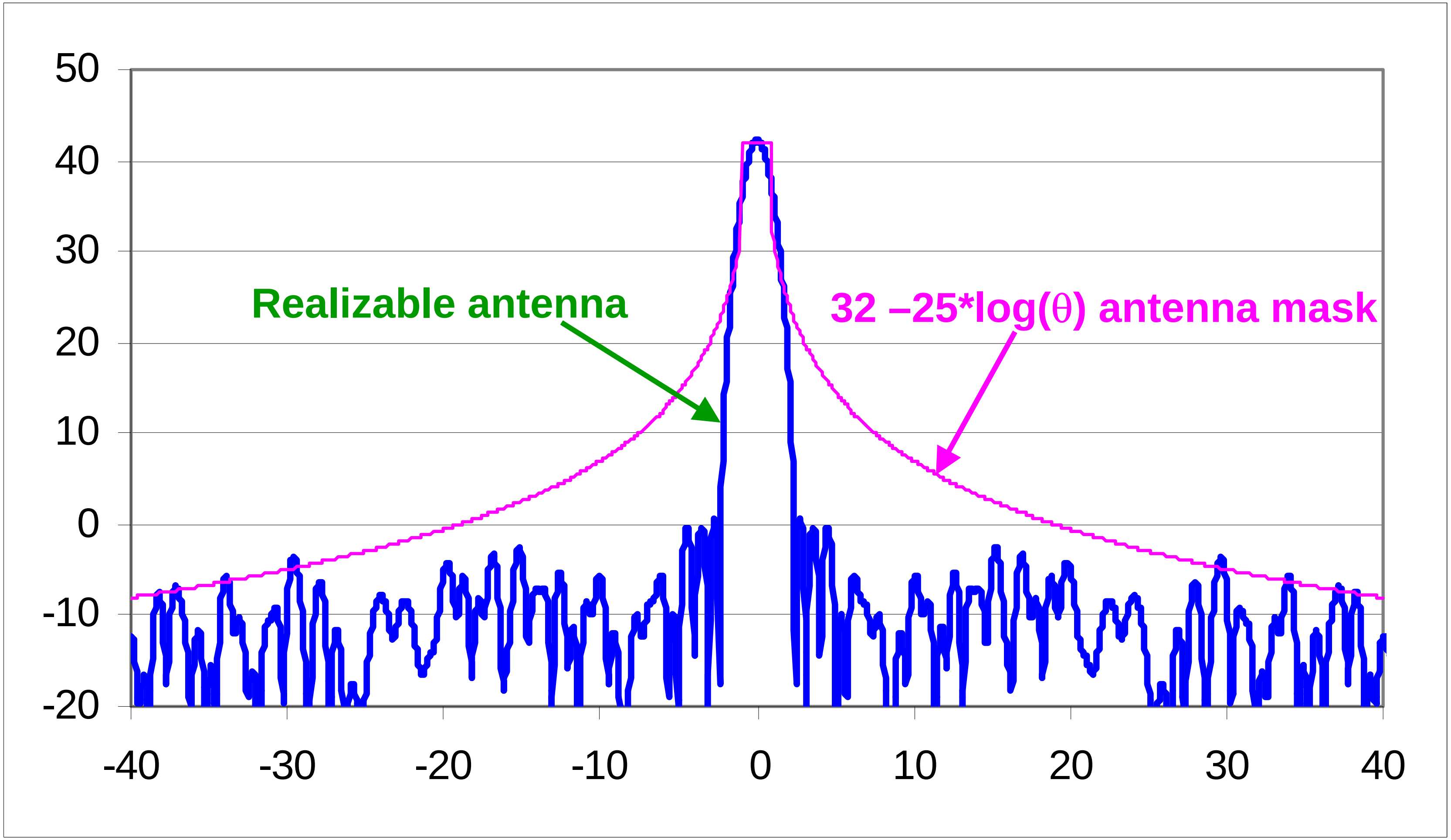


Siting the FSS earth terminal to prevent blockage is the driving force in ability to see satellites

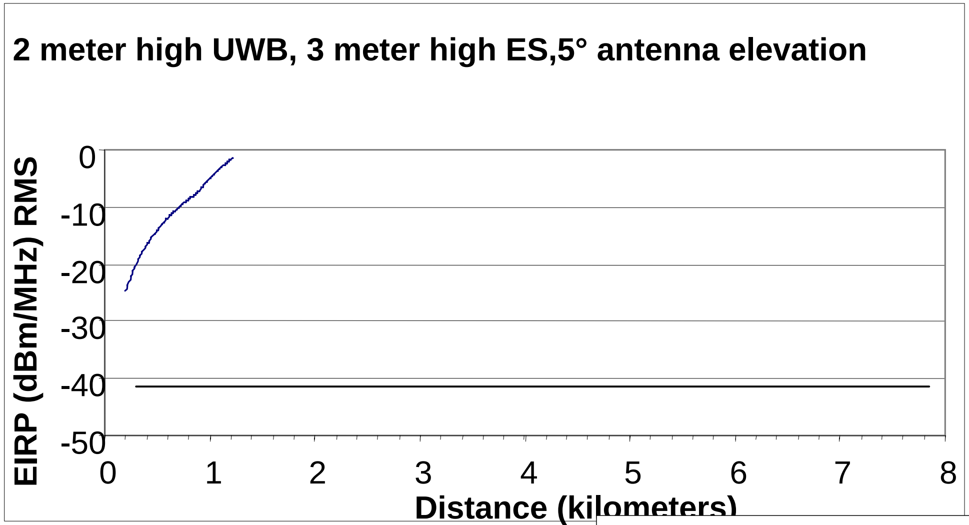
Changes from NTIA Analysis

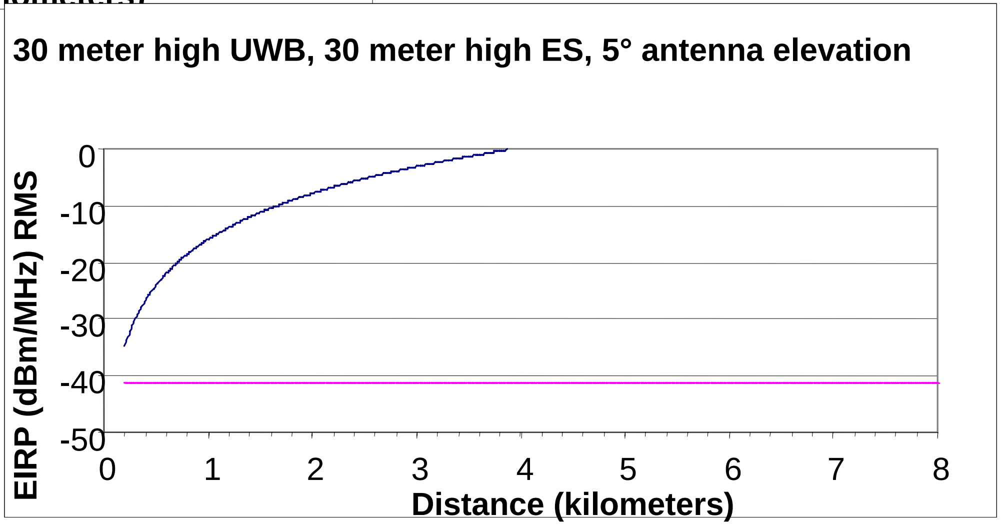
- **Circular polarization (3 dB change from NTIA report)**
- **165° K Noise temperature at 5° elevation (15° change from NTIA report)**
- **Antenna**
  - The FCC has a worst-case sidelobe “mask” for the Transmit antenna, (25.209)
  - NTIA used a modified FCC (25.209) transmit antenna mask and forced the gain to be 42 dBi between ± 1°, as is standard practice. – But…it is not real.
  - This beam shape goes against physics and conservation of energy
  - This beam pattern requires the antenna to radiate more power than it gets
- **Real antennas with a 1/2-power beamwidth of 2°, have a mainbeam that drops faster than the assumed beam pattern**
  - The sidelobes and nulls in real antennas cannot be avoided because of their finite aperture.
- **As a result, as a UWB device moves closer to the antenna, the UWB signal drops faster because it is going down the side of the mainbeam.**

FSS Antenna Pattern



Permitted UWB Transmit Power, Given I/N = *-6dB vs Distance From the 4 GHz FSS Earth Station*





FSS Earth Station Summary

- **Siting the FSS earth terminal to prevent blockage is the driving force in ability to see satellites**
- **A 30m High Outdoor Class-B UWB Device is Safe**
  - If the outdoor Class-B UWB device on the roof of a 30m tall building is close enough to make a difference, Then the building blocks the beam.
    - A 3m high FSS antenna aimed at 5° elevation is blocked by a 30m tall building 200 m away
    - An outdoor Class-B UWB device at 30m height cannot raise the FSS noise floor by 1 dB until it is closer than 200m to the 5° elevation beam
- **A 2m high outdoor Class-B UWB Device is Safe**
  - The UWB device must be closer than 60 meters to raise the noise floor by 1dB
    - Based on a constant –10 dBi sidelobe FSS antenna at 3 meters height
  - Raising the FSS antenna up to a roof avoids the antenna blockage problem and provides even more protection from UWB devices.

FSS needs no protection from elevated or ground-level outdoor pedestrian Class-B UWB devices

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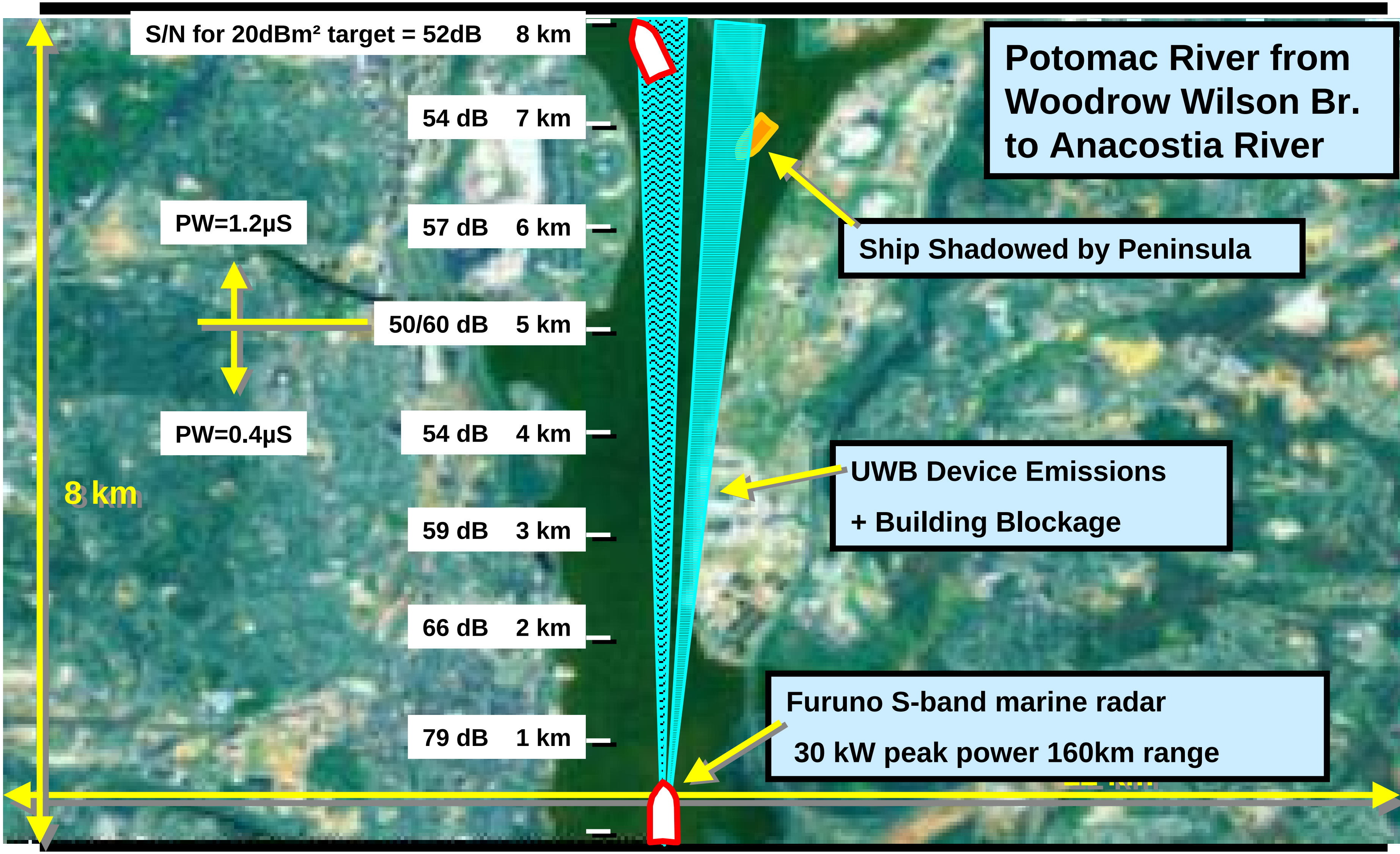
Maritime Radar – What it is

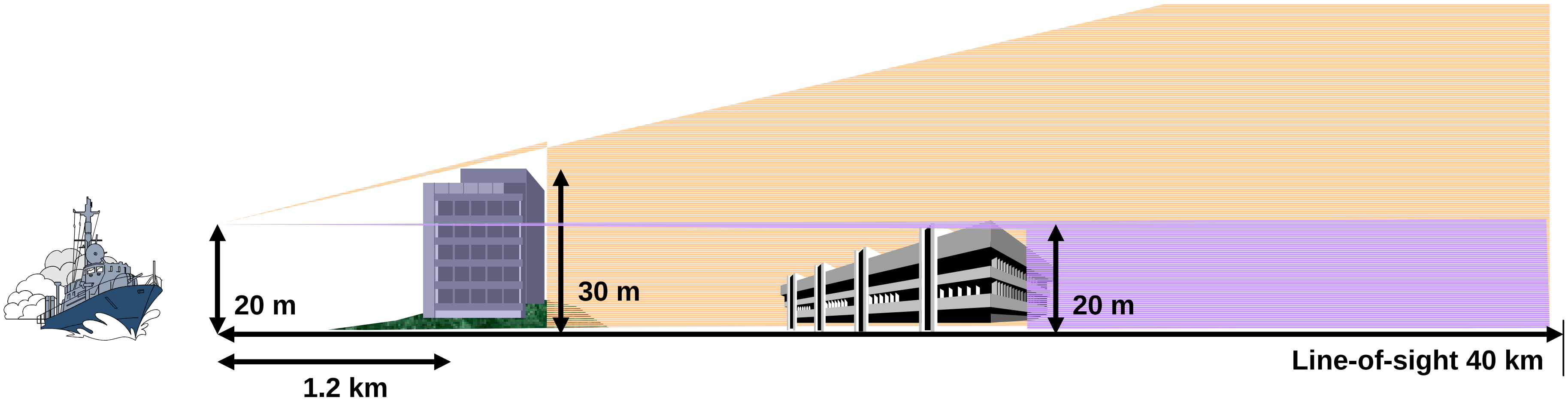
- **Mission is to prevent ships from hitting shorelines or each other**
- **Example: Furuno S-band Marine Radar – Fit's NTIA spreadsheet**
  - 30 kW peak power into antenna
  - 27dBi Gain Antenna

    15 MW EIRP
    - The narrow beam width (1.9°)
    - Azimuth sidelobes are at least 30 dB down (1000 times smaller than main lobe) beyond 10 degrees off the main lobe.
  - 3.05 GHz,
  - 20m Height,
  - 4 dB NF+2dB losses,
  - 4 MHz bandwidth (–104 dBm Receiver Noise Floor)
  - Pulse Width
    - 1.2μs for > 5km
    - 0.4μs for < 5km
- **A Robust Radar**
  - Spec'd to 160 km even though the radar horizon is less than 30 miles

Maritime Radar Waterway Peninsula Scenario --Radar May See UWB Devices Closer than a Ship

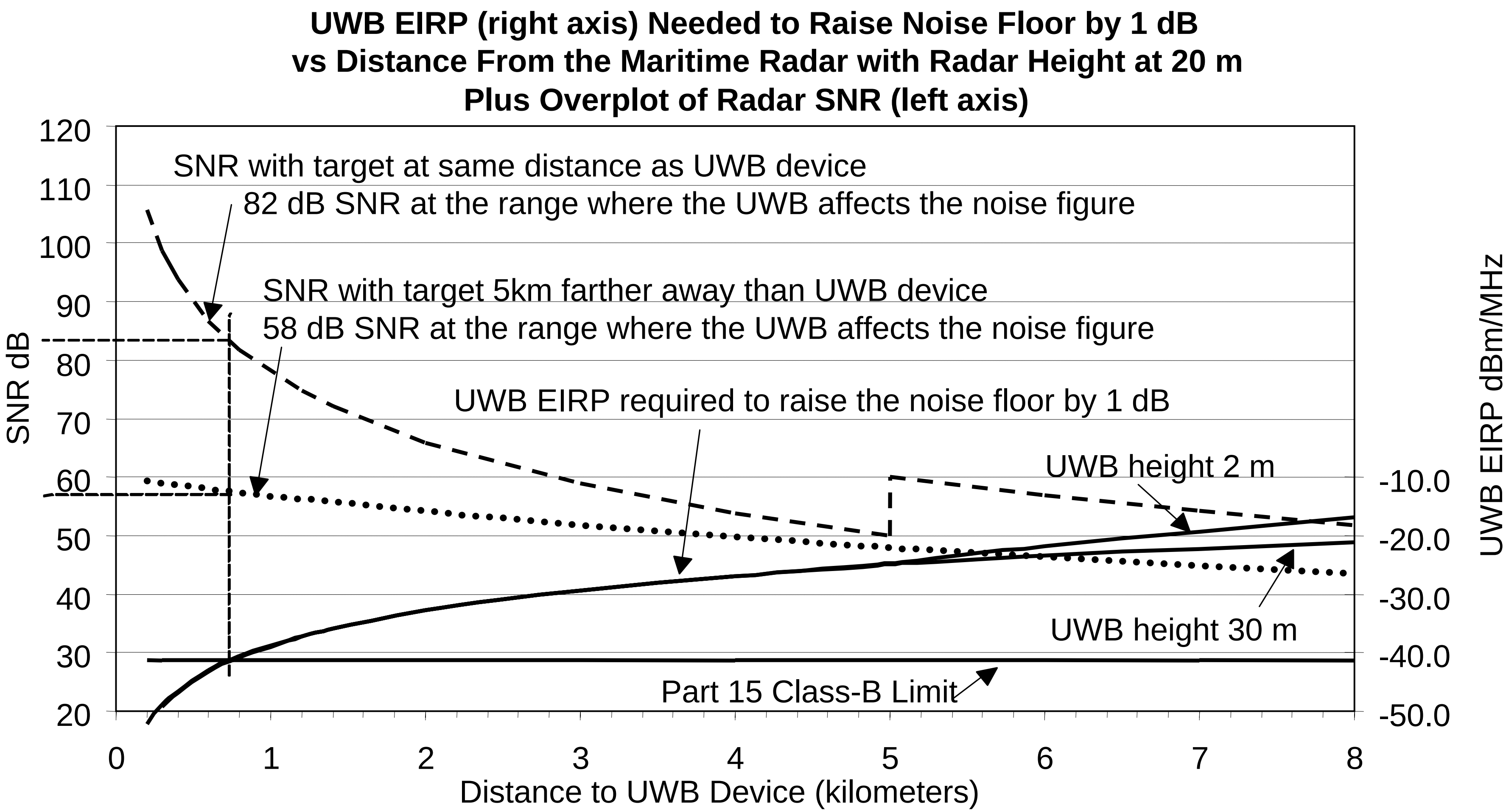


Note Blockage by Buildings Causing Shadow on Ship in Potomac River



Marine Radar SNR and Noise Calculations

- **The High SNR Precludes Class-B UWB Emissions From Being a Factor**



Maritime Radar Summary

- **The functional limit of the maritime radar is not the system noise floor.**
- **When the ship is close enough to land for an outdoor, 30 m elevated Class-B UWB device to raise the noise floor by 1 dB**
  - The desired signal is millions of times stronger than the UWB emissions (82 to 57 dB SNR from example on previous slides)
  - The land clutter coming through the integrated antenna sidelobes is thousands of times stronger than the UWB emissions
  - The UWB emissions have NO effect on the radar's function
  - There is NO harmful interference.
- ***Maritime radars need no protection from elevated or ground-level outdoor pedestrian Class-B UWB devices***

Outline

- NTIA Study
  - SNR *not Noise Figure* as metric for harmful interference
  - Lack of Aggregation

Pg	GHz	System	Outdoor Limit Required	Limit Relative to Class-B
14	5.6-5.65	TDWR Terminal Doppler Weather Radar	– 41.3 dBm/MHz	0 dB
18	5.03-5.09	MLS Microwave Landing System	– 41.3 dBm/MHz	0 dB
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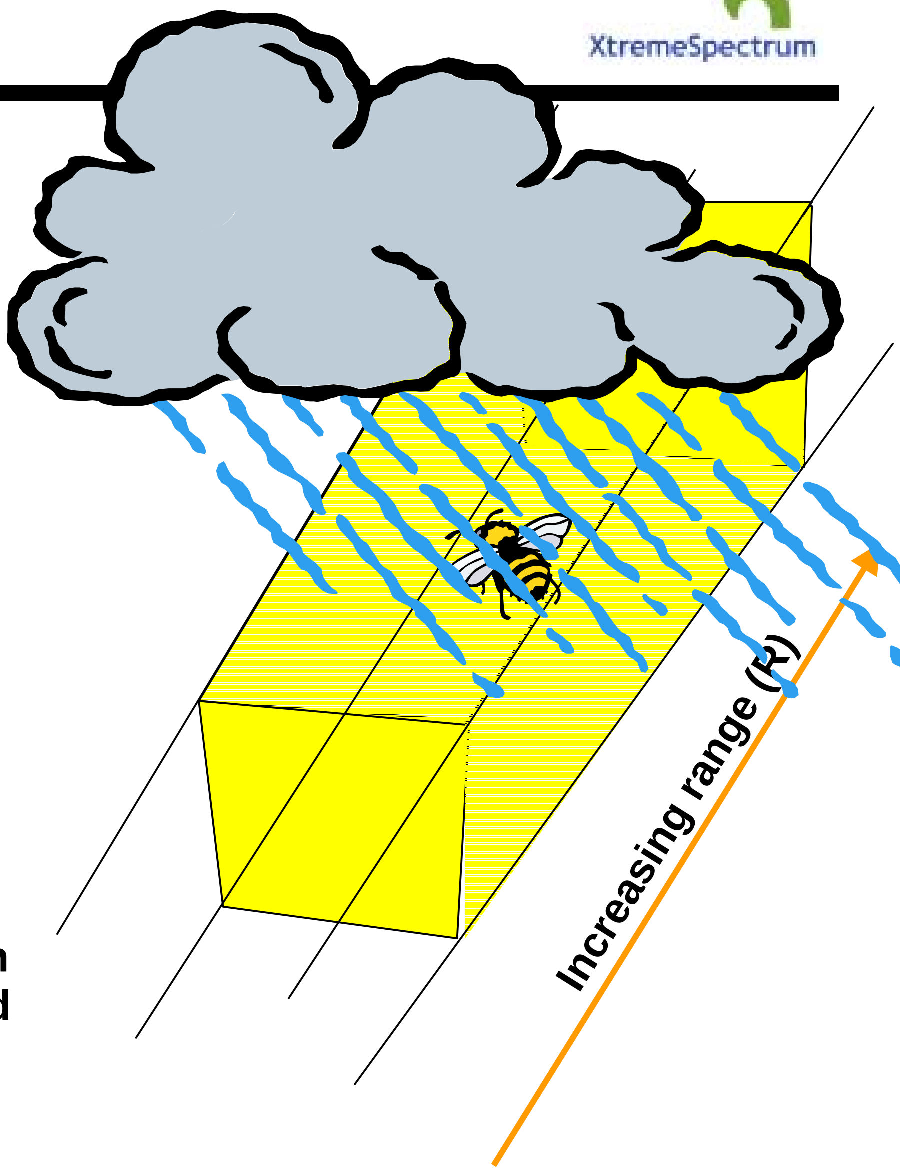
26	2.9-3.1	Maritime Navigation Radar	– 41.3 dBm/MHz	0 dB
32	2.7-2.9	NEXRAD Next Gen Weather Radar	– 41.3 dBm/MHz	0 dB
35	2.7-2.9	ASR-9 – Airport Surveillance Radar	– 41.3 dBm/MHz	0 dB
40	1.57542, 1.2276	GPS L1 & L2 Spectral Lines	– 70.0/-76.3 dBm	– 28.7/-35 dB*
49	1.544-1.545	SARSAT Local User Terminal (LUT)	– 70.0/-76.3 dBm	– 28.7/-35 dB*
52	1.24-1.37	ARSR-4 –Air Route Surveillance Radar	– 41.3 dBm/MHz	0 dB
55	1.025 – 1.15	DME Transponder (Ground Station)	– 59.3 dBm/MHz	– 18 dB

* - RTCA/GPSIC limits

- Other Topics
  - Similarities to Emissions from PC's
  - UWB does not imply spectral lines

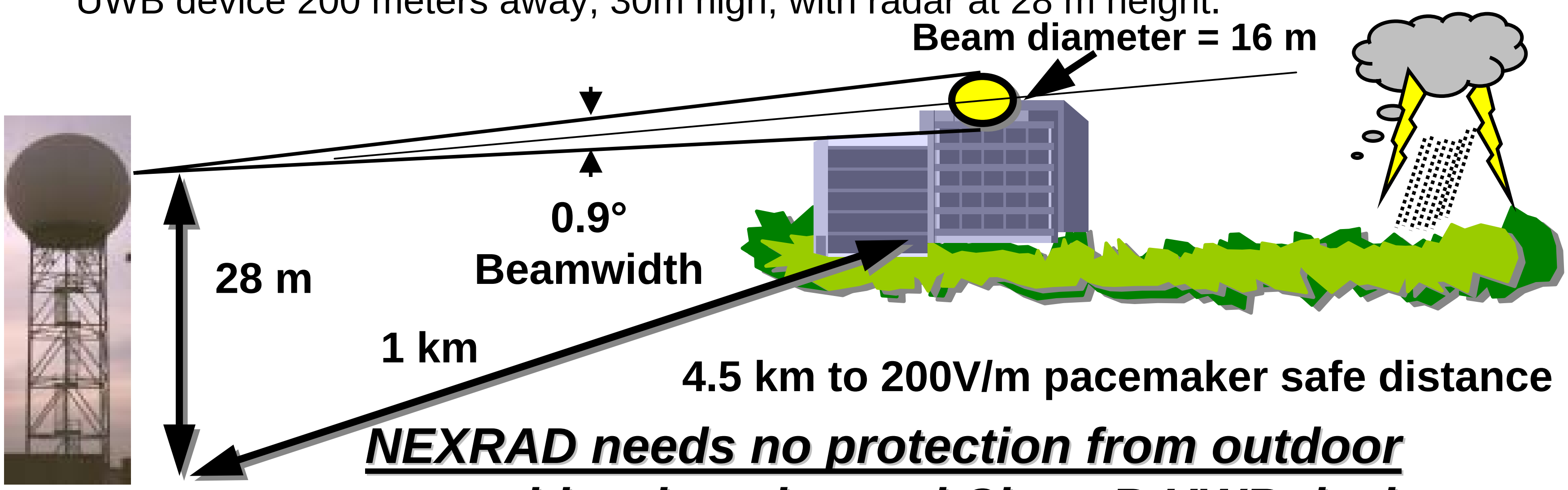
NEXRAD
– What it is

- **Spec's are:**
  - 2.7-3.0 GHz
  - 750 KW peak, 300-1300 W Average
  - 45.5 dB gain Antenna (.925° spot beam)
  - -113 dBm/500KHz noise floor
- **NEXRAD is an extremely powerful radar – radiating 26.6 GW peak and 46 MW average EIRP in the main beam.**
- **The RadHaz (200 V/m) distance for pacemakers is 4.5 km**
- **It is circularly polarized and has a 3 dB coupling loss to UWB signals**
- **Weather radars sense volumes (voxels). These voxels grow with range since the flashlight beam radiated spreads with distance. So they lose sensitivity slower than other radars – by a factor of only $1/R^2$ instead of $1/R^4$ with R=range, allowing them to see farther.**



NEXRAD
Limitation is not the noise floor

- **The radar is clutter limited, NOT noise floor limited,**
  - The radar is designed to operate on what others call “clutter” and is known in the radar community as being “clutter limited” not “noise limited.”
- **Weather backscatter signals are large and give high Signal-to-Noise ratios:**
  - For example: Imagine a dry light snow (i.e. worst case smallest target for a weather radar; -5 dBz) at long range (400 km) with 100 km of intervening heavy rain (representing a factor of 100 extra loss; 20 dB).
  - Energy coming back from the snow is 1000 times stronger (30 dB) than the noise of a UWB device 200 meters away, 30m high, with radar at 28 m height.



<u>NEXRAD needs no protection from outdoor ground-level or elevated Class-B UWB devices</u>

Outline

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  - **SNR *not Noise Figure* as metric for harmful interference**
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- **Other Topics**
  - **Similarities to Emissions from PC's**
  - **UWB does not imply spectral lines**

ASR-9 Air Surveillance Radar – What it is

XtremeSpectrum

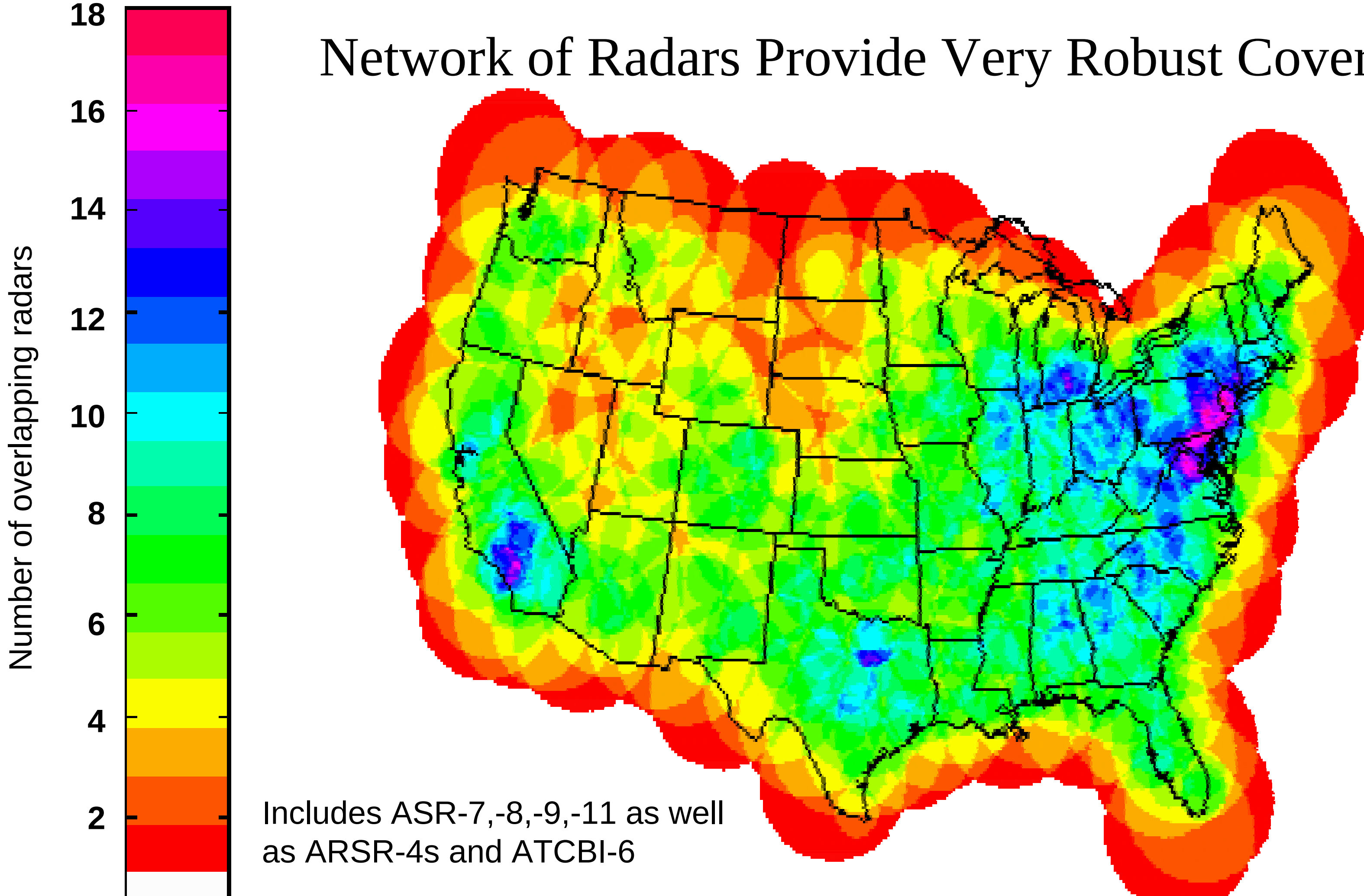
- **Mission is to monitor aircraft in the airspace in and around airports**
- **Radar Parameters**
  - Dual 1.3 Megawatt Transmitters
  - 33.5 dBi Gain Antenna
    - Narrow azimuth beamwidth (1.4°)
    - Cosecant squared elevation pattern

  2.9 GW EIRP

  - **1.4 km range to 200V/m Pacemaker Radiation Hazard**
  - Max Range 110 km.
  - 2.7-2.9 GHz,
  - 17 m Average Height,
  - 4 dB NF+2 dB losses,
  - 4 MHz bandwidth (–104 dBm Receiver Noise Floor)
  - Pulse Width 1.08 μs
  - PRF dithered from 928 up to 1321 pulses/sec
  - 8 and 10 pulse CPI (Doppler coherent processing interval)
- **Very Robust Surveillance Radar**
  - 300 times more signal than needed (25 dB margin) on passenger Jets at maximum range

Surveillance Radar Coverage Overlap

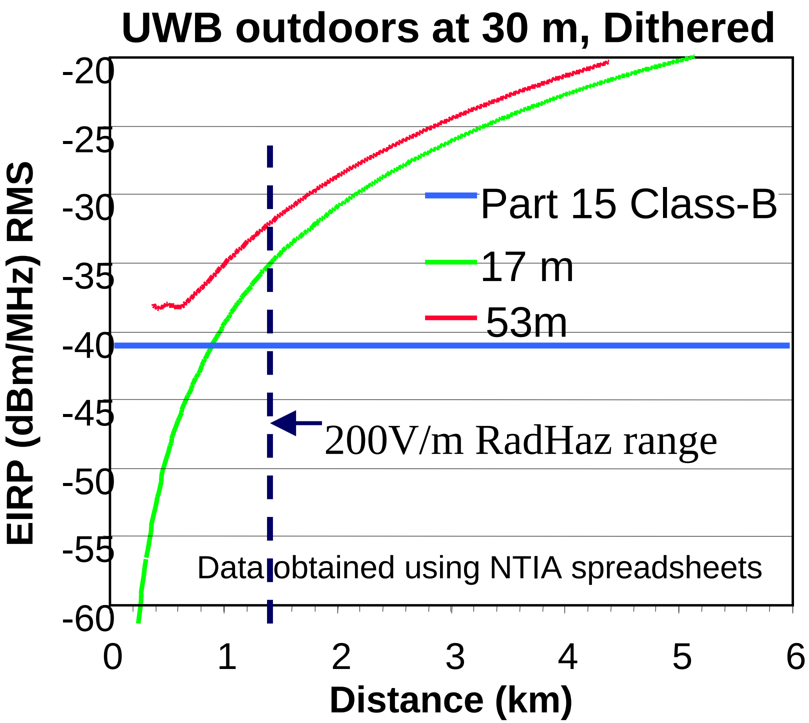
Network of Radars Provide Very Robust Coverage

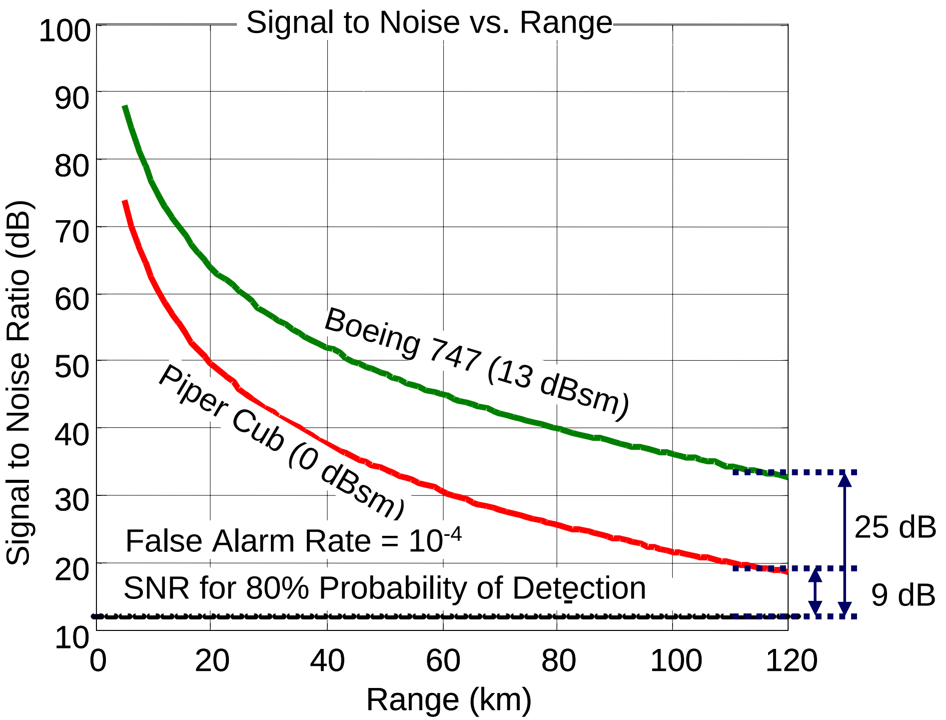


Source: "Analysis of Radar Coverage Overlap Over the Continental U.S." AIAA Digital Avionics Systems Conference October, 1999. Includes SSR radars planned, but as of 1999, not yet installed.

ASR-9

- **Class-B UWB device cannot raise noise floor without being in the RadHaz zone.**
- **9 dB SNR margin to track piper cub at 110 km**
- **25 dB margin for passenger jet**





ASR-9 Summary

- **An outdoor class-B UWB device elevated 30m cannot raise noise floor even 1 dB without UWB user being in the RadHaz zone.**
- **An outdoor class-B UWB device on the ground never raises the noise floor 1 dB because is falls out of the beam**
- **The noise floor is not the limiting factor**
  - The signal is more than 10 times louder than it needs to be even for a small 2-seat piper cub airplane.
  - The signal is more than 300 times louder than it needs to be for a passenger jet

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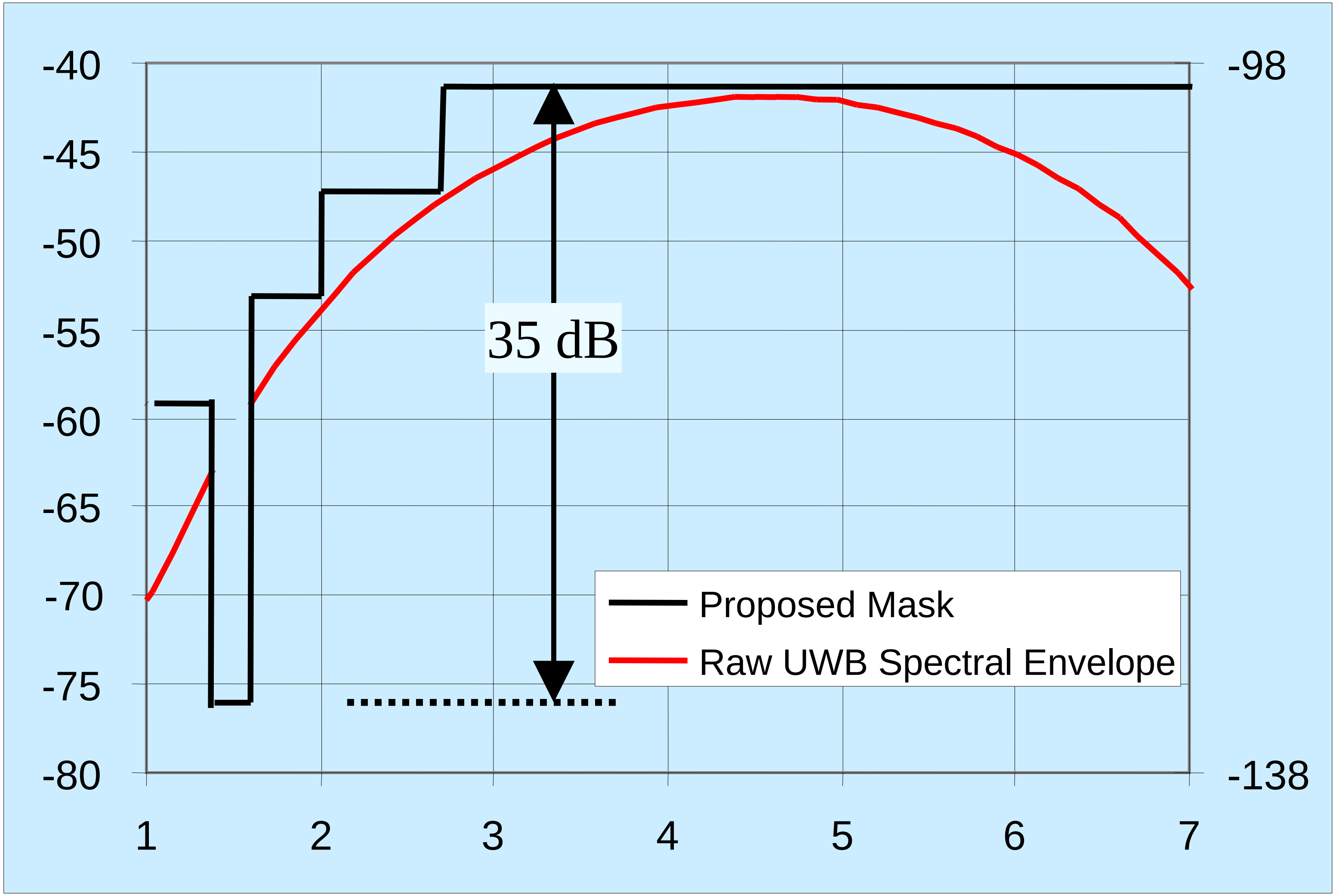
* - RTCA/GPSIC limits

- **Other Topics**
  - **Similarities to Emissions from PC's**
  - **UWB does not imply spectral lines**

GPS -- XSI Has Gone On Record Accepting 35 dB Protection

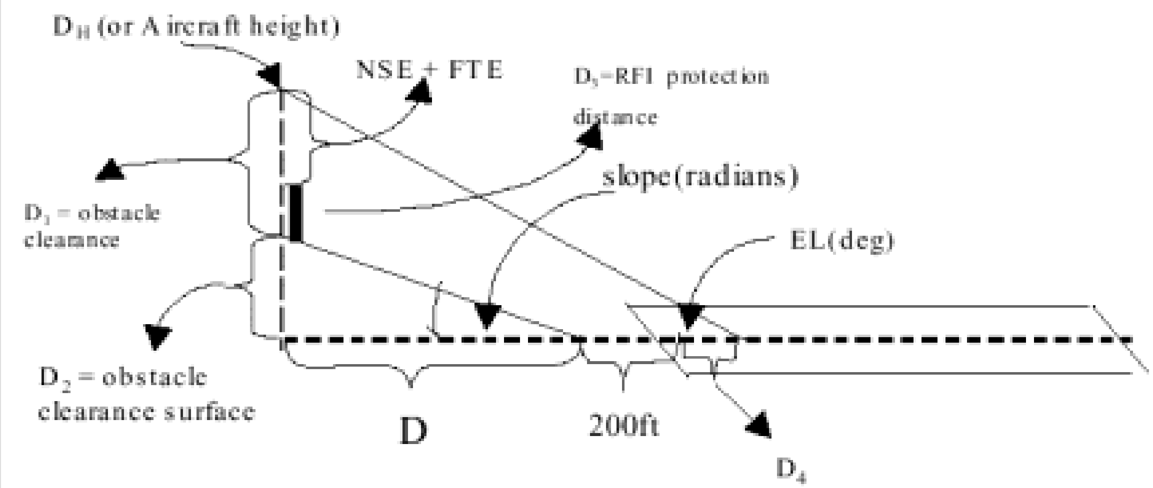


XSI's Proposed Rules are Safe for GPS Precision Approach Landings

- **RTCA Report PMC-139 does an evaluation of UWB interference to precision approach landings**
- **The calculation shown on the next page assumes:**
  - The UWB Devices are all in the worst possible location
  - 10 UWB devices, all transmitting 100% of the time
  - 1 MSS terminal emitting RFI at –70 dBW/MHz to the GPS unit
  - To account for the MSS (mobile satellite service, e.g. Iridium) RFI, the calculation forces the UWB devices to be 10 dB weaker.
    - This even though the UWB emissions must be stronger to add the equivalent noise figure of the GPS unit, and the UWB signal is drowned out by the MSS emissions
  - The UWB units are assumed to have spectral lines in the GPS band
    - 10 dB lower levels for tones.
- **The emission limit computed is –100 dBW/MHz for tones, and –90 dBW/MHz for noise.**
- **This level is 18.7 dB down from Part 15 Class-B limits, 28.7 dB down for lines, and is essentially equal to the rules proposed by XSI.**

Category II Precision Approach

XtremeSpectrum



Aircraft antenna height above control point = 7ft

EL = 3 deg

D_H = 100 ft CAT II

D_4 = 50/tan(EL) ft

D = D_H/tan(EL) - D_4 - 200 = 754.1 ft for CAT II

slope = 1/50 for CAT II/III

D_2 = D*slope = 15.1 ft

Obstacle Clearance = D_1 = D_H - D_2 = 84.9 ft

aircraft antenna-to-obstacle surface = 84.9 + 7 = 91.9 ft

*RTCA Calculations**

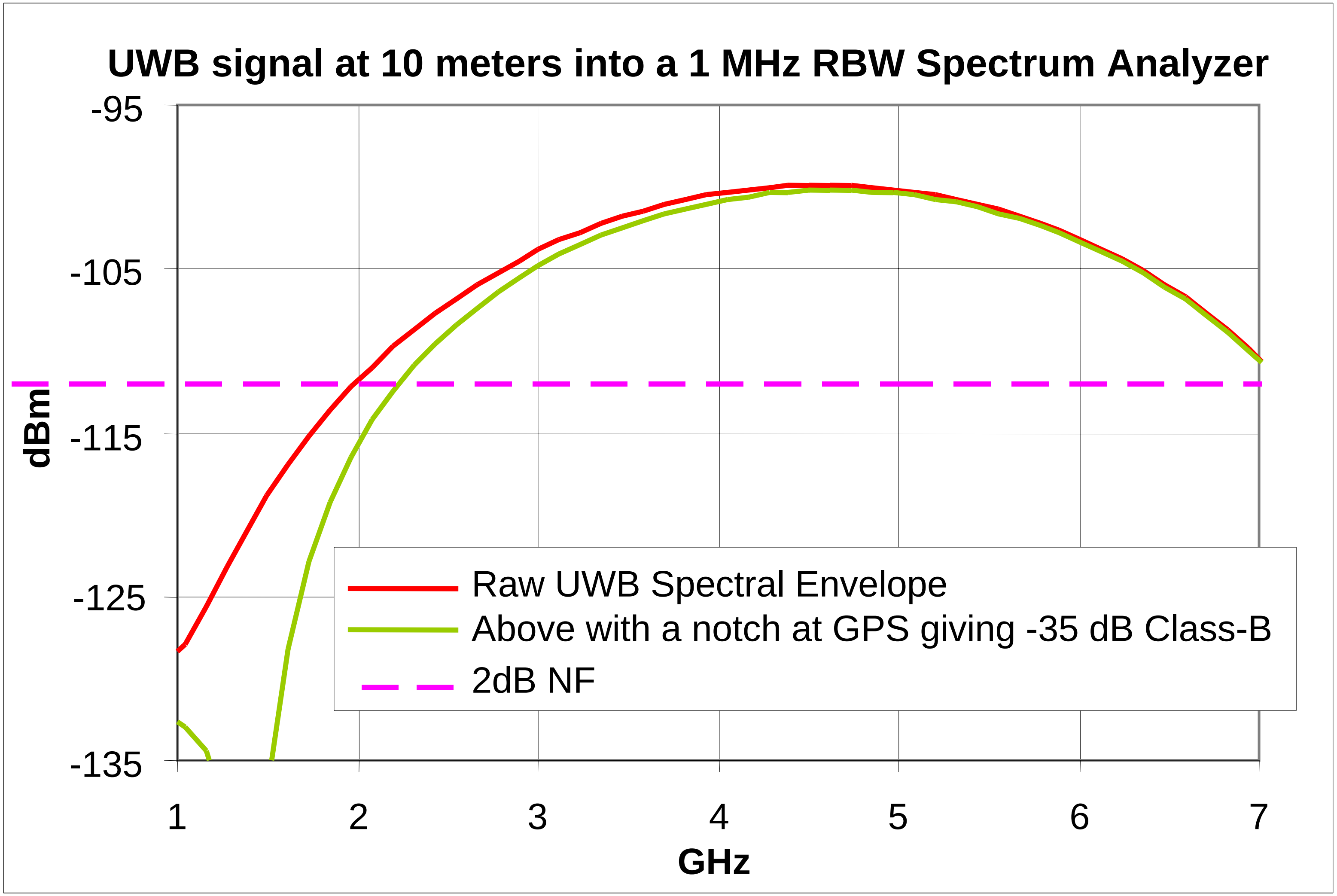
- **XSI told FCC it will not oppose the GPSIC request for –106 dBW/MHz (3000 times lower power (35 dB) than Class-B limits)**
- **This is 6 dB more than RTCA recommended**

	GPS WAAS/LAAS Category I	GPS LAAS Category II/III
Frequency	1575 MHz	1575 MHz
Receiver Susceptibility Mask (broadband noise)	-140.5 dBW/MHz	-140.5 dBW/MHz
Aeronautical Margin	-5.6 dB	-5.6 dB
Total Allowed Broadband RFI (at receiver input)	-146.1 dBW/MHz	-146.1 dBW/MHz
Worst-Case UWB Noise Equivalent Correction Factor (note 1)	-10 dB	-10 dB
Multiple System Allotment (excluding MSS)	-10 dB	-10 dB
Single Emitter Allotment (note 2)	-10 dB (strawman value until data available)	-10dB (strawman value until data available)
UWB RFI @GPS receiver	-174.1 dBW/MHz	-174.1dBW/MHz
Antenna gain toward RFI source	10 dB	13.1dB
Propagation Loss (separation distance)	66.1 dB (100ft)	63.0 dB (70ft)
RFI Emission Limit	-100 dBW/MHz	- 100 dBW/MHz

- 1 Assumes Spectral Lines
- Makes UWB weaker since MSS is so Noisy
- 2 Assumes 10 emitters at closest point
- Bottom line is 100dBW for spectral lines.

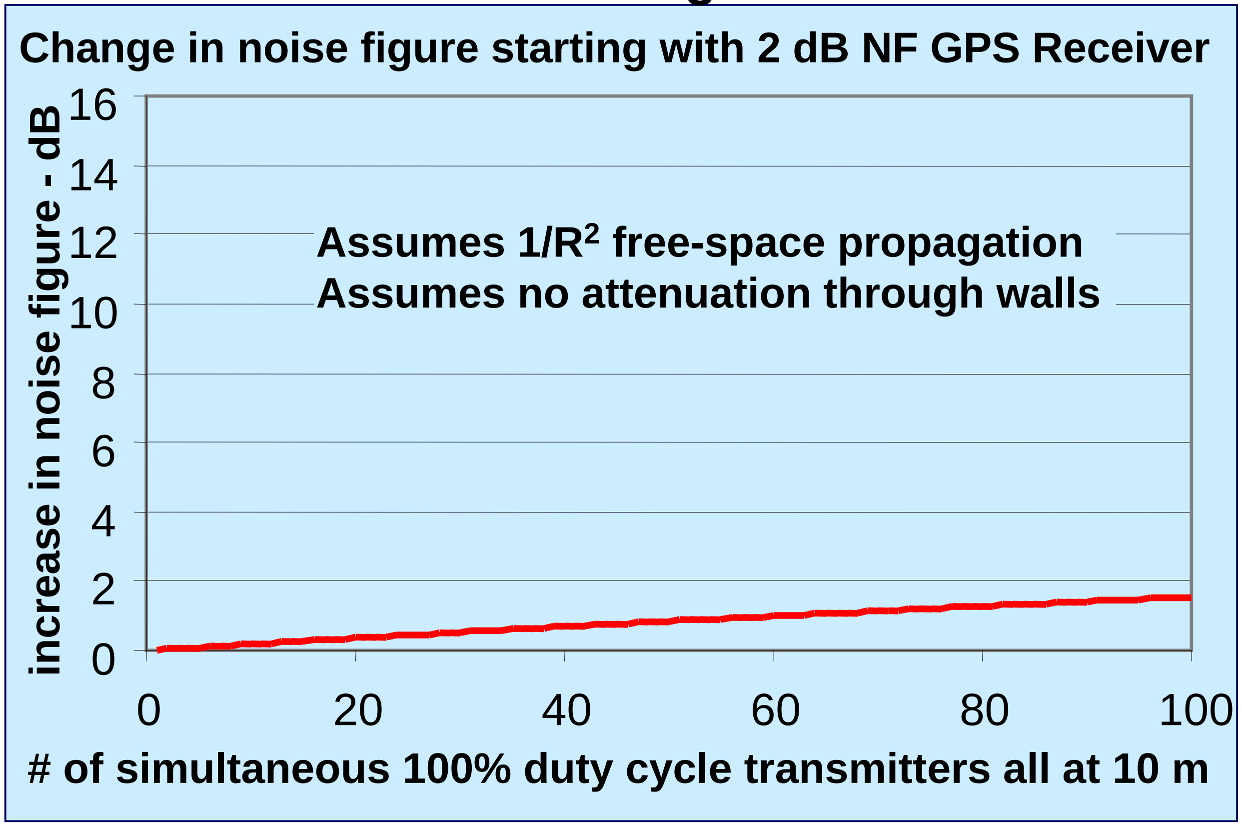
Table 4.2 from RTCA Paper No. 086-01/PMC-139, Second Interim Report to the Department of Transportation: Ultra-Wideband Technology Radio Frequency Interference Effects to Global Positioning System Receivers and Interference Encounter Scenario Development, RTCA SC-159, 27 MAR 2001

Noise Power in a 1 MHz Bandwidth



Negligible Change in GPS' Effective Noise Figure

- **100 UWB devices at –35 dB-Class-B (–76.3 dBm/MHz) all transmitting simultaneously just 10 m from a GPS only raises a 2 dB Noise Figure GPS unit to the equivalent of a 3.5 dB Noise Figure**



- **even in this unrealistic density of active devices, there is clearly**

***no harmful interference*–**

Interference To Assisted GPS

- **Assisted-GPS units obtain 20 to 30 dB of additional processing gain over and above a standard GPS C/A code receiver.**

- **Key point is that the additional processing (i.e. longer integration times) is equivalent to a narrower filter bandwidth**
  - It passes the GPS signals and rejects noise (or anything that does not look like the desired GPS signal)

- **The UWB signal is suppressed along with everything else**

- **An assisted-GPS unit is no more sensitive to UWB interference than a normal GPS unit.**
  - i.e. The noise floor of the A-GPS unit may drop from –130 dBm to –150 dBm, but the effective bandwidth is 100 times smaller so 20 dB less UWB noise can get in.
  - A UWB transmitter does not need to drop its power by 20 dB

GPS Summary

- **GPS can be completely protected with a deep notch**
- **RTCA's conservative analysis asked for –60 dBm/MHz for noise and –70 dBm/MHz for spectral lines**
- **GPSIC asked for –76.3 dBm/MHz protection for spectral lines**
- **XSI filed that it believed these were overly conservative but would not object.**
- **The analysis shows that this level is exceedingly safe**

- ***<u>GPS can be protected from outdoor UWB devices, both at ground-level and elevated heights</u>***

Outline

- **NTIA Study**
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  - **Lack of Aggregation**

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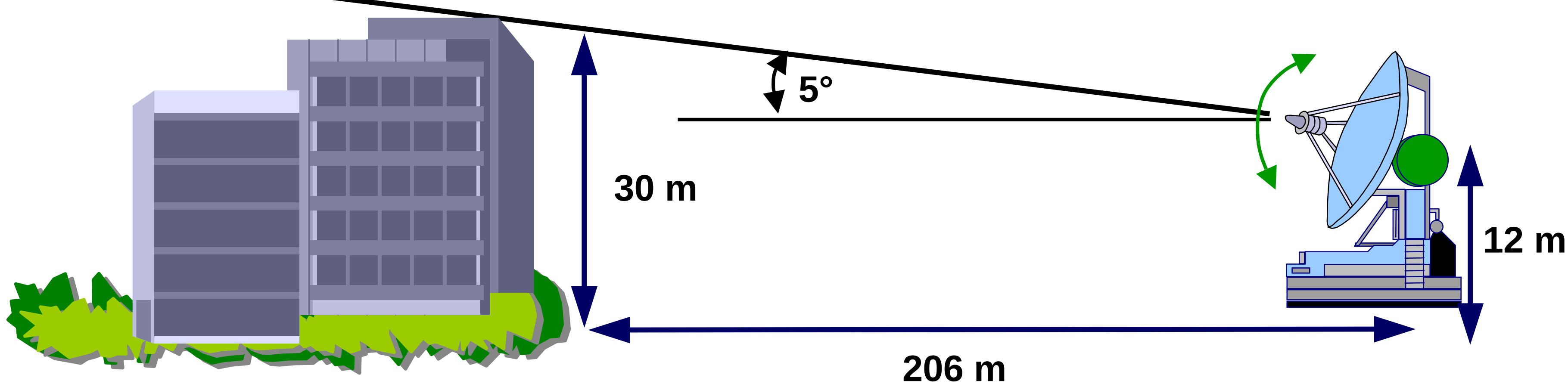
* - RTCA/GPSIC limits

- **Other Topics**
  - **Similarities to Emissions from PC's**
  - **UWB does not imply spectral lines**

Satellite Receiver Example:
SARSAT Local User Terminal (LUT)

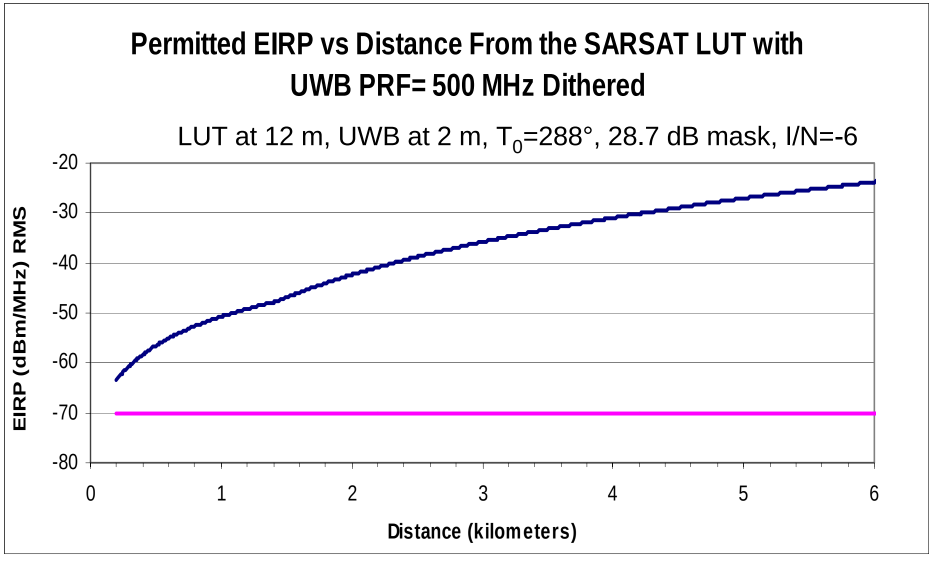
- Satellites Listen for Emergency Beacons at 122 and 406 MHz and forward info to the LUT.
- SARSAT spec is to operate down to 5° except where prevented by local obstructions
- Time between 0-5° is ~30 seconds for high angle orbits
  - LEO (low earth orbit) satellites with 100 minute orbital periods

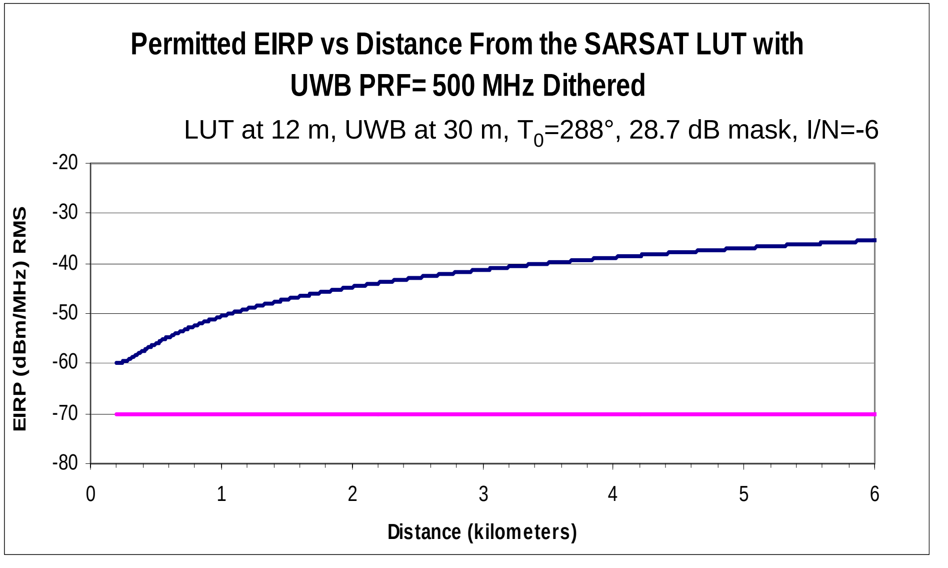
Factors neglected: Mask
- XSI spectral mask of 18 dB
- RTCA mask of 28.7 dB
- GPSIC mask of 35 dB



SARSAT Local Users Terminal (Ground Station)

- With proposed –70dBm/MHz RTCA limit, protection criteria is not exceeded to closer than 200 m limit of ITM at 0° elevation.
- Will operate within SARSAT specification if buildings are far enough away to allow 5° operation (206 m)





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  - UWB does not imply spectral lines

ARSR-4 -- What it is

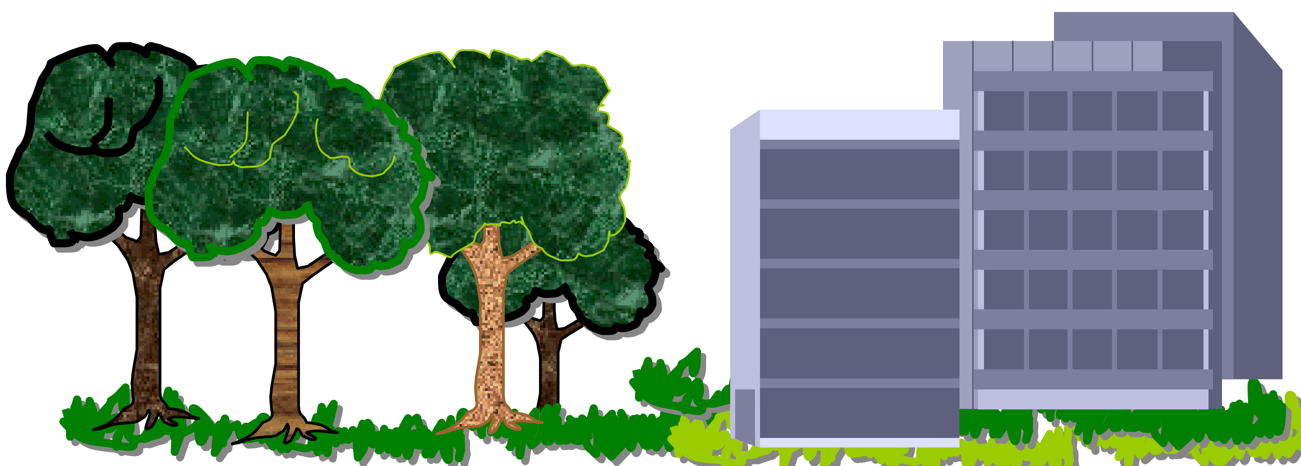
- **Mission: Air route surveillance RADAR**
- **Specifications**
  - Frequency 1215 - 1400 MHz
  - 3 MW Peak (ARSR-3)
  - Antenna
    - Maximum gain 41.8dBi
    - Nine vertically stacked beams with different gains
    - Beam One 3 dB Beamwidth Vertical 2.0, Horizontal 1.4 Degrees
  - 5.8 km to 200 V/m Pacemaker RadHaz
  - Max Range 250 nm (463 km)
  - Performance requirement is 200 nm for 2.2 m2 RCS target
  - Noise Floor -113 dBm
  - Pulse Width   2.2 µsec (ARSR-3)
  - Pulse Width 1 µsec (ARSR-4)

45.4 GW EIRP

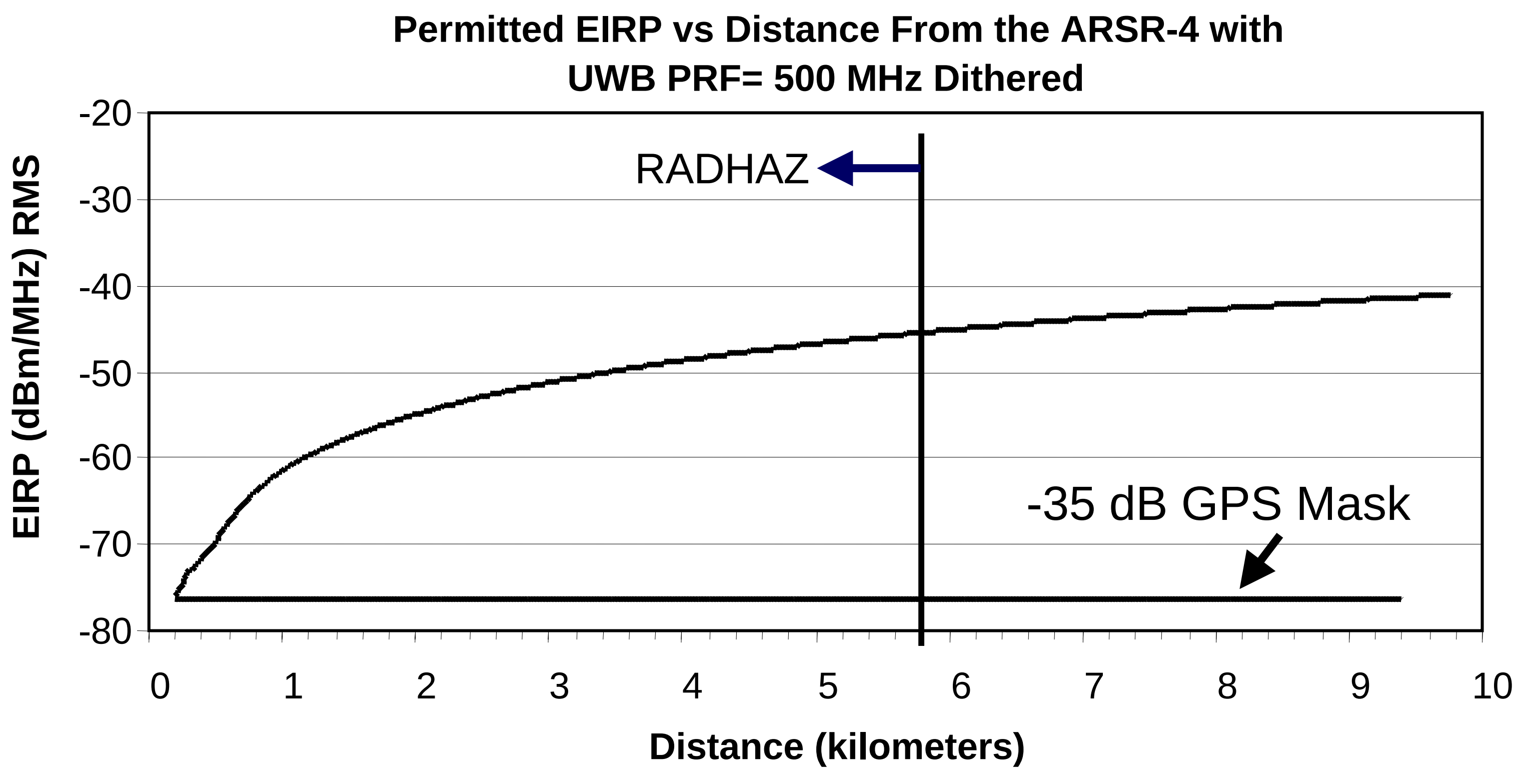
ARSR-3 & 4
Air Route Surveillance Radars

- **Key Factors: Signal Strength, siting, and additional mask protection.**
  - Spectral Mask 35 dB at ARSR-4 frequency
- **Beam is aimed above buildings and other obstructions**
  - to avoid ground clutter
  - to avoid radiation hazard to pacemakers

With UWB at 30 meters there is a 0 dB margin at 200 meters with respect to the protection criteria. At this range, radiation hazard is the problem.



ARSR - 4 Interference versus Range UWB Elevated 30 Meters



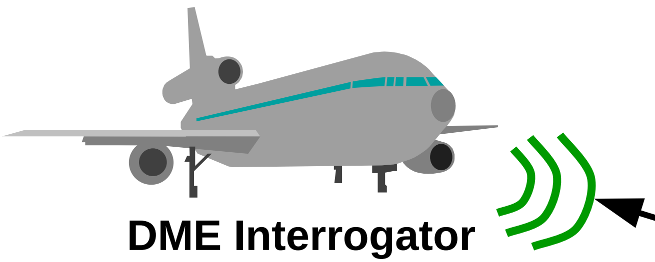
GPS Mask (-35 dB) sets onset of interference at 200 meters

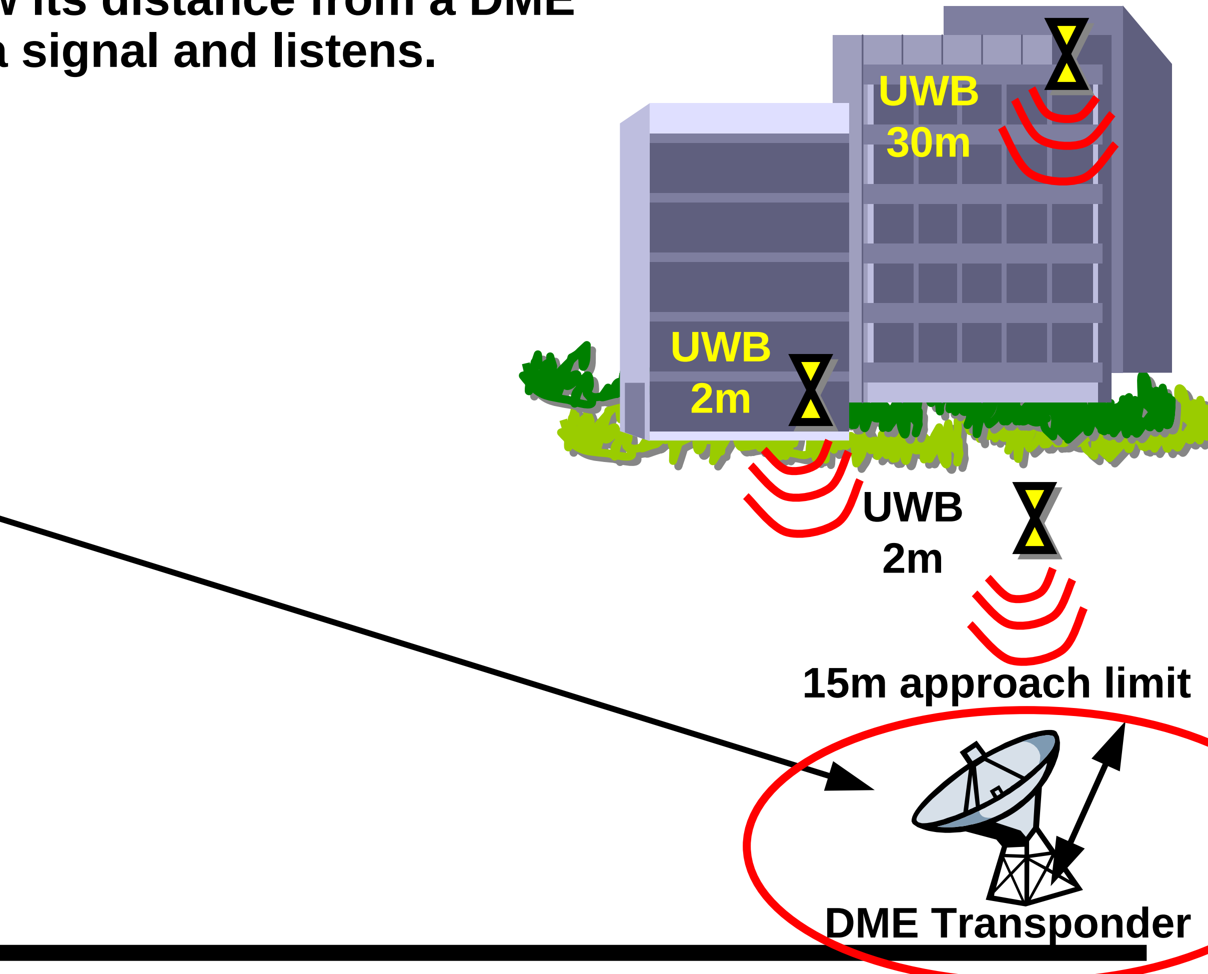
ARSR-4 radars operate with ground-level and elevated outdoor pedestrian –45.3 dBm/MHz UWB devices at the 5.9 km RadHaz range

DME Transponder (Ground Station)

XtremeSpectrum

- **Distance Measuring Equipment**
- **If airline want to know its distance from a DME transponder, it fires a signal and listens.**

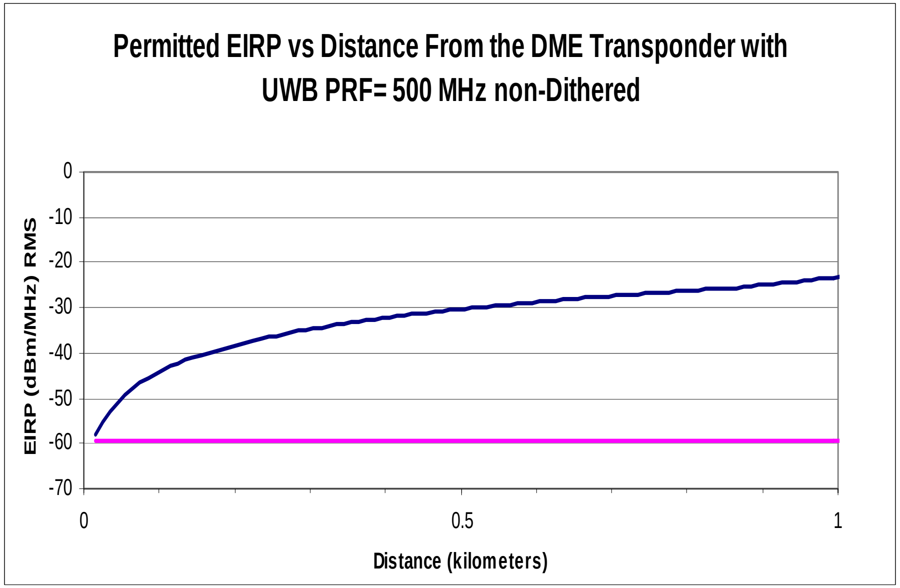


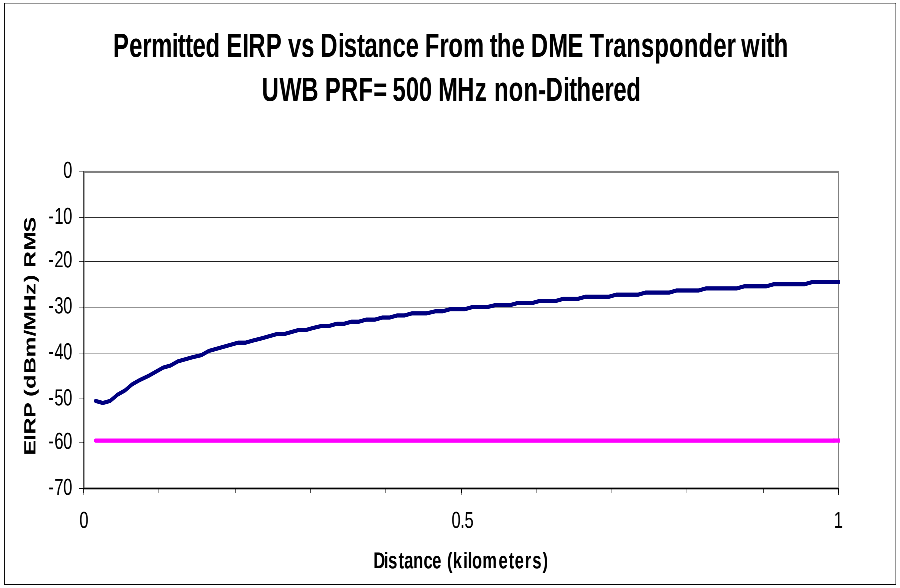


Additional factors neglected:
XSI spectral mask of 18 dB
RTCA margin of 28.7 dB
GPSIC margin of 35 dB

DME ground station

- The DME transponder is not receiver-noise limited
- At the worst case maximum range of 240km at 18km (50 k ft) altitude there is 18-20 dB excess SNR *above* the 70% reply level
- Applying the spectral mask, with a –10 dB I/N, the UWB device at 2 meters elevation has a 2 dB margin, while the UWB device at 30 m has a 9 dB safety margin
- A UWB is safe even at the protection fence 15m away
- A GPS notch filter would provide 11 – 18 dB more protection





Conclusions

- **No Peer-to-Peer Restrictions are needed**
  -- A Simple Restriction On Tower Mounted UWB Devices is Plenty
  - Sound technical analysis supports that a spectral mask provides all the needed protection to allow UWB devices to operate outdoors.
- **Outdoor Class-B UWB at any height and scenario is safe for GPS**
  - Numerous reports and studies present a consistent picture of the interference mechanisms of UWB on GPS receivers
  - The 35 dB down from Class-B accomplishes the needed protection
- **Outdoor Class-B UWB at any height is safe for all systems studied in NTIA report**
  - Assumptions that changed will be highlighted in following slides
- **Aggregation is not a factor**
  - Numerous reports and studies present a consistent picture showing the cumulative effects of multiple UWB devices are dominated by closest emitters
  - Experience from PC's is that aggregation is not an issue.
- **Emissions and Aggregation from a PC are representative**
  - UWB signals are similar from those of PC's and other typical radio signals.
  - If a device is not bothered by PC's, then it won't be bothered by UWB

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35	2.7-2.9	ASR-9 – Airport Surveillance Radar	– 41.3 dBm/MHz	0 dB
40	1.57542, 1.2276	GPS L1 & L2 Spectral Lines	– 70.0/-76.3 dBm	– 28.7/-35 dB*
49	1.544-1.545	SARSAT Local User Terminal (LUT)	– 70.0/-76.3 dBm	– 28.7/-35 dB*
52	1.24-1.37	ARSR-4 –Air Route Surveillance Radar	– 41.3 dBm/MHz	0 dB
55	1.025 – 1.15	DME Transponder (Ground Station)	– 59.3 dBm/MHz	– 18 dB

* - RTCA/GPSIC limits

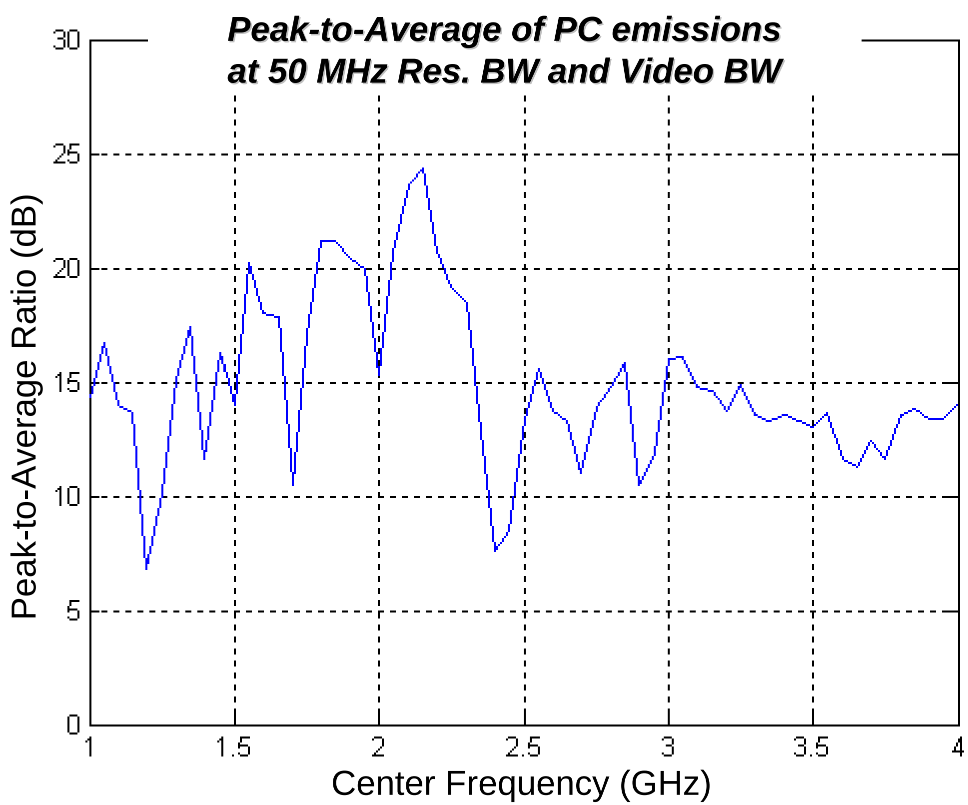
- **Other Topics**
  - **Similarities to Emissions from PC's**
  - **UWB does not imply spectral lines**

The Ubiquitous PC Is Appropriately Similar (Peak to Average)

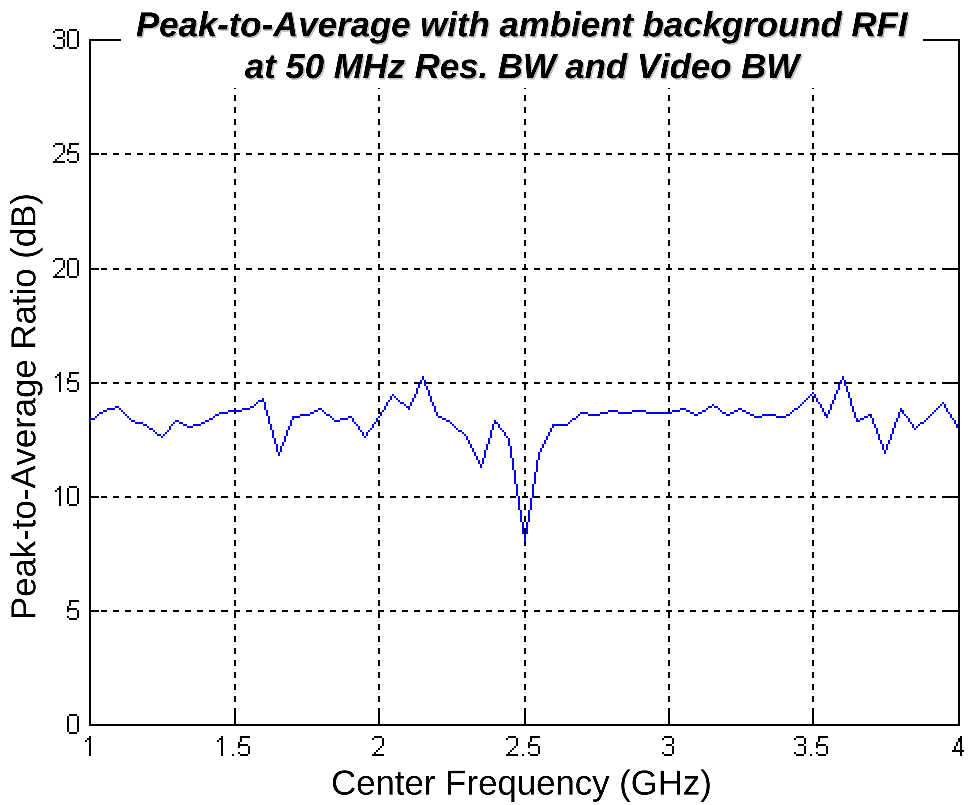
XtremeSpectrum

- **We know that there is no interference due to an aggregation of ubiquitous digital devices – like PC's, cell-phones, PDA's, printers, etc.**
  - Even extremely high densities in homes and offices don't cause interference.
  - The 450 MHz PC verified for the UT Austin tests easily passed the type B standard, **yet had a spectral line at –57.3 dBm at GPS 1575 MHz**
- **PC emissions are measured, well known, and not different from UWB**
  - PC's *do* generate sub nanosecond rise times and impulse noise.
  - The peak-to-average ratio of radiation from PC's is usually around 18 dB in a 4 GHz resolution bandwidth, < 25 dB in a 50 MHz bandwidth, and < 30 dB in a 1 MHz bandwidth.
- **UWB radiation is not different**
  – It can be regulated to be similar to a PC
  - UWB emissions do not have to be higher peak-to-average signals
  - The next slides show measurements of the peak-to-average ratio of background RFI, emissions from a PC, and an XSI UWB transmitter running continuously.

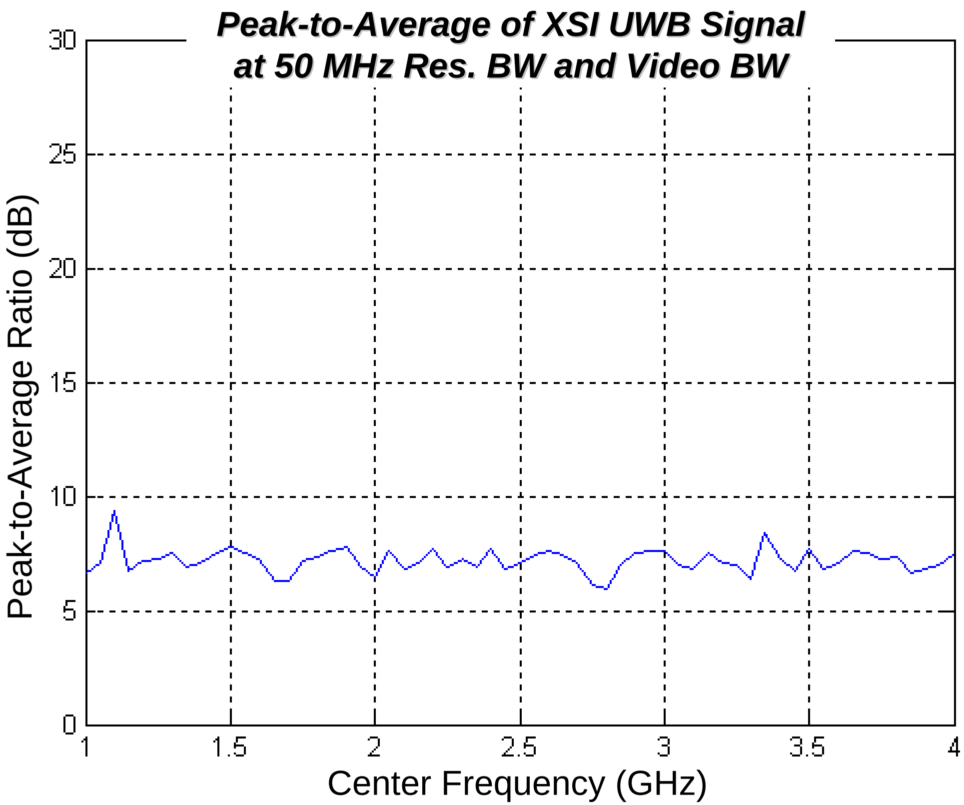
Peak-to-Average of PC at 50 MHz Res. BW and Video BW



Peak-to-Average with ambient background RFI at 50 MHz Res. BW and Video BW



Peak-to-Average of XSI UWB Signal at 50 MHz Res. BW and Video BW



The Ubiquitous PC Is Appropriately Similar (Interference Level)

- **Some argue that UWB and PC emissions are different and that UWB may cause "more" interference because**
  - A PC emits nearly Class-B levels only at a few frequencies, but
  - A UWB device emits nearly Class-B levels over a very wide range of frequencies,.
- **HOWEVER, any victim conventional narrowband receiver doesn't know the difference– it doesn't know what the bandwidth of the source is.**
  - If the PC is at Class-B levels in the passbands of 10 victim receivers and it causes no interference to any of the 10,
--Then the Class-B levels from the UWB device that are in the same passbands of the same 10 receivers will also not cause interference.
  - The fact that the UWB device may, at the same time, be at Class-B levels in the passbands of 10 additional receivers, is of no consequence, because similarly, just like a different PC with Class-B levels in these receivers' passbands does not cause interference to them, again the UWB does not interfere with those receivers either
- **If Class-B works for PC's and other digital devices,
Then it also works for UWB**
  - History has proved that it HAS worked,
  - ***Even with numerous and increasing and clock frequencies***

Outline

- NTIA Study
  - SNR *not Noise Figure* as metric for harmful interference
  - Lack of Aggregation

Pg	GHz	System	Outdoor Limit Required	Limit Relative to Class-B
14	5.6-5.65	TDWR Terminal Doppler Weather Radar	– 41.3 dBm/MHz	0 dB
18	5.03-5.09	MLS Microwave Landing System	– 41.3 dBm/MHz	0 dB
20	3.7-4.2	FSS Fixed Satellite System Earth Station	– 41.3 dBm/MHz	0 dB
26	2.9-3.1	Maritime Navigation Radar	– 41.3 dBm/MHz	0 dB
32	2.7-2.9	NEXRAD Next Gen Weather Radar	– 41.3 dBm/MHz	0 dB
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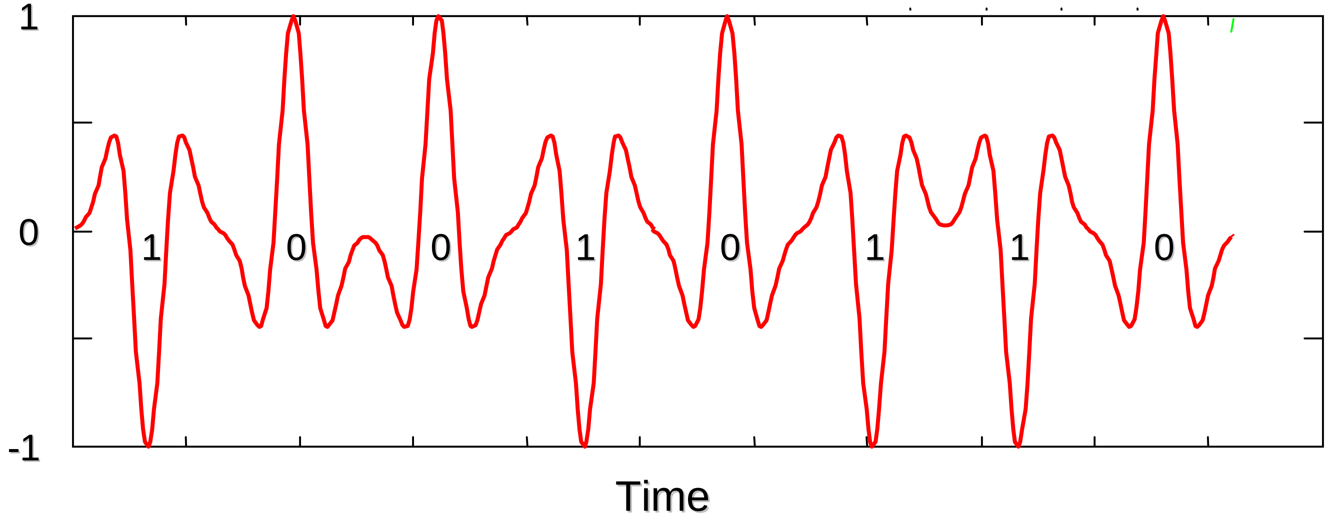
- Other Topics
  - Similarities to Emissions from PC’s
  - UWB does not imply spectral lines

A General Expression for a UWB Waveform

- **Like many conventional narrowband digital communications systems, UWB systems encode data into a transmit waveform by modulating a basic pulse shape either in phase, amplitude or using time delays with the source bits.**
- **The properties of transmit waveform can be understood through analysis of the modulation process, and are based on assumptions about the statistics of the source data.**
- **The first step is a representation of the transmit waveform *s(t)* as the sum of time-shifted versions of a basic pulse shape *p(t)* modulated by pulse weights a_k corresponding to the source data bits:**

$$s(t) = \sum_{k=-\infty}^{\infty} a_k p(t - t_k)$$

A General Expression for a UWB Waveform



- The figure above shows such a series of pulses where the weights used are +1 and –1 (corresponding to data bits 0 or 1). Notice that for this particular signal the peak-to-average ratio of the waveform is quite similar to a sinusoidal-based waveform.
- The main point here is that using the analytical representation of this waveform, we can easily find its spectrum and understand how to control spectral lines.

A General Expression for a UWB Waveform

$$s(t) = \sum_{k=-\infty}^{\infty} a_k \, p(t - t_k)$$

- **The general case is where the *k-th* bit is encoded on a pulse delayed by t_k seconds and multiplied by the pulse weight a_k that depends on the data bit to be sent.**
- **For amplitude modulation, the choices for a_k correspond to different amplitudes (e.g. $a_k \in \{0,1\}$ for on-off keying).**
- **For phase-shift keying, the a_k would simply change the polarity of the pulse based on the data, so $a_k \in \{-1,+1\}$**

An Expression for a Uniform UWB Pulses

$$s(t) = \sum_{k=-\infty}^{\infty} a_k\, p(t - t_k) = \sum_{k=-\infty}^{\infty} a_k\, p(t - kT_b)$$

- **This second expression shows a special case of the first where the individual pulses are uniformly spaced, so t_k is replaced by kT_b, where T_b is the bit-interval.**
- **This form can represent many modulation types including on-off keying (OOK), pulse-amplitude modulation (PAM) or binary phase-shift keying (BPSK).**
- **In general, we assume that the source data are random and un-correlated. In real systems it is relatively simple to sufficiently "whiten" the data with pre-procssing to make the transmitted a_k random and un-correlated.**

Finding the Spectrum of a UWB Waveform

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- **The power spectral density (PSD) of a random signal can be found by taking the Fourier transform of the autocorrelation of the signal (this is covered in many texts on digital communications).**
- **For the signals described above, this results in a PSD of:**

$$\Phi_{SS}(f) = \left|P(f)\right|^2 \Phi_{AA}(f)$$

- **Here the PSD of the signal ($\Phi_{SS}(f)$) is seen to depend on the magnitude of the Fourier transform of the original pulse *P(f)* = FT{ *p(t)* }) and the spectrum of the data sequence, $\Phi_{AA}(f)$.**

Finding the Spectrum of a UWB Waveform

- **Our assumption that the data bits are uncorrelated allows us to substitute for the spectrum of the data ($\Phi_{AA}(f)$) in terms of the mean and the variance of the bit weight sequence, a_k:**

$$\Phi_{ss}(f) = \frac{\sigma_a{}^2}{T_b}\left|P(f)\right|^2 + \frac{\mu_a{}^2}{T_b{}^2}\left|P(f)\right|^2 \sum_{m=-\infty}^{\infty} \delta(f - \frac{m}{T_b})$$

- **The first term in this resulting expression is a continuous function (in frequency).**
  - Its shape depends only on the shape of the original pulse (*p(t)*).
  - Its power is weighted by the ratio of the variance of the data bits ($\sigma_a{}^2$) and the the bit interval T_b.
- **The second term is a sum of frequency-shifted impulses that represent the “spectral lines” of the signal.**
  - The power in these lines is seen to be proportional to the mean-squared ($\mu_a{}^2$) of the sequence a_k divided by the bit-interval squared $T_b{}^2$.
  - The frequency spacing of the lines is the inverse of the bit-interval, so the lines (when present) are spaced at the pulse-repetition frequency (PRF).
- **So a zero-mean data sequence (μ_a=0) will not have spectral lines.**

UWB Waveform with NO Spectral Lines

- **We can now clearly see that the mean of the data weight sequence provides a way to remove UWB spectral lines completely.**
- **If we use a modulation techniques for which the sequence mean is ZERO, then the spectral lines vanish, and we are left with a PSD that is simply a continuous function of frequency with no lines:**

$$\Phi_{SS}(f) = \frac{\sigma_a{}^2}{T_b} \left| P(f) \right|^2$$

- **This zero mean condition is met with BPSK signaling.**
- **Note that in the case where the spectral lines vanish, the PRF has no affects on the spectral distribution of signal energy**
  - The PSD assumes the smooth shape of the Fourier Transform of the original pulse, and the PRF has no affect.
  - The PRF affects only the average power.